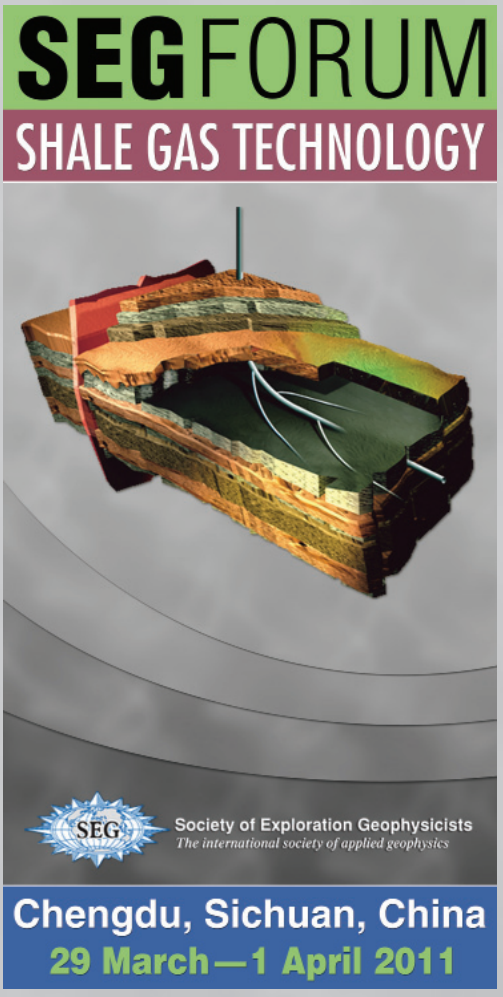
Official Program



Society of Exploration Geophysicists
The international society of applied geophysics

NATIONAL ENERGY SHALE GAS R&D CENTER

Shale Gas Technology Forum

29 March – 1 April 2011

Shangri-La Hotel

9, Binjiang Dong Road • Chengdu, 610021 China • (86 28) 8409-7313

Welcome to Chengdu!

SEG Shale Gas Technology Forum
29 March – 1 April 2011


Dr. Alfred L. Liaw

On behalf of the Organizing Committee, I would like to welcome you to Chengdu, Sichuan and the SEG Shale Gas Technology Forum. Whether this is your first visit to this historic city or you come here often, you will leave after this trip and this Forum with lifetime memories and a better understanding of the technology applicable to develop shale resources.

Over the past 10 months, the Organizing Committee has been working diligently to give you a rewarding Technical Program. Thanks to the suggestions by the CNPC leadership who requested SEG to take the lead in organizing this historic forum on shale gas development, the Organizing Committee has been collaborating with the Chinese Petroleum Society (CPS)/Society of Petroleum Geophysics (SPG) and the National Energy Shale Gas R&D Center. Nearly half of the registered attendees come from three national oil companies (CNPC, Sinopec, and CNOOC) and their subsidiaries in China. Due to popular demand, registration has more than doubled from the original expectations and we have expanded the Technical Program to three days.

The Forum's Technical Program has been organized into the following six sessions:

- Shale gas business and outlook
- Geology and rock physics of shale reservoirs
- Geophysics techniques for shale reservoirs
- Drilling, fracturing, and resource assessment
- Microseismics for fracture monitoring and in-situ stress estimation
- In-situ stress and rock properties

I hope that this Forum will provide some insight about the potential that shale reserves play in North America as well in China, and that you also understand the critical factors controlling the successful development of shale resources. Please take advantage of the networking opportunities during the Forum to understand how to effectively apply state-of-the-art technology for enhancing production from shale gas reservoirs.

The Organizing Committee recognizes there are many things to do in Chengdu in addition to the Forum and encourages you to explore the history and the natural beauty of Sichuan Province while you are here. Thanks for supporting the SEG Shale Gas Technology Forum.

Dr. Alfred L. Liaw
Chairman, Organizing Committee
Vice President, SEG

Cover image courtesy of Saudi Aramco.

Shale Gas Technology Forum • 29 March – 1 April 2011

Shangri-La Hotel • 9, Binjiang Dong Road • Chengdu, 610021 China • (86 28) 8409-7313

PROGRAM

Objective: To provide a technical exchange platform for the technologies related to shale gas plays and the trend of shale gas development and exploitation.

Forum Organization Committee:

Chairman, Alfred L. Liaw (Anadarko, SEG Vice President)
Vice Chairman, Shufa Dwan (Shell)
Guozhen Zhang (CNPC)
Jianhui Feng (Sinopec)
Shoujun Wang (CNOOC)
Arthur Cheng (Halliburton)
Sheng Ding (Newfield)
Wenjie Dong (ExxonMobil)
Peter Duncan (MicroSeismic, Inc.)
Bill Keller (Chesapeake)
Randal LaFollette (Baker Hughes)
Yan Li (Chevron)
Tom Neville (Schlumberger)
Galen Treadgold (Global Geophysical)
Jie Zhang (Chinese University of Science and Technology)
Ziqiong (ZZ) Zheng (Baker-Hughes)

SCHEDULE

Tuesday 29 March

1–8 p.m. ..... Registration Open *(Hotel first floor)*
4–5 p.m. ..... Session Chairs Meeting *(He Jiang Room, hotel first floor)*
6:30–8:30 p.m. ..... Icebreaker *(Mian Yang Ballroom, hotel second floor)*

Wednesday 30 March

7:30–9 a.m. ..... Registration *(Outside of Ya An Ballroom, hotel second floor)*
8:30–9:50 a.m. ..... Opening Ceremony *(Ya An Ballroom, hotel second floor)*
9:50–10:10 a.m. ..... Coffee Break
10:10 a.m. – 12 p.m. ..... Session 1
12–1 p.m. ..... Lunch *(Mian Yang Ballroom, hotel second floor)*
1–5:05 p.m. ..... Session 2
2:40–3 p.m. ..... Coffee Break
5–6 p.m. ..... Panel Discussions
6:30–8:30 p.m. ..... Dinner *(Mian Yang Ballroom, hotel second floor)*

Thursday 31 March

8:30 a.m.–12 p.m. ..... Session 3 *(Ya An Ballroom, hotel second floor)*
9:45–10 a.m. ..... Coffee Break
12–1 p.m. ..... Lunch *(Mian Yang Ballroom, hotel second floor)*
1–5:05 p.m. ..... Session 4
2:40–3 p.m. ..... Coffee Break
5:30 p.m. ..... Buses depart
6:30–9 p.m. ..... PetroChina Cultural Night

Friday 1 April

8:30 a.m.–12 p.m. ..... Session 5 *(Ya An Ballroom, hotel second floor)*
9:45–10 a.m. ..... Coffee Break
12–1 p.m. ..... Lunch *(Mian Yang Ballroom, hotel second floor)*
1–4:15 p.m. ..... Session 6
2:40– 3 p.m. ..... Coffee Break
4:15 p.m. ..... Adjourn

EMERGENCY CONTACTS:

Gary Liu 186-1012-2718
Jackie Liu 139-1668-5850
Alfred Liaw 131-2297-4390

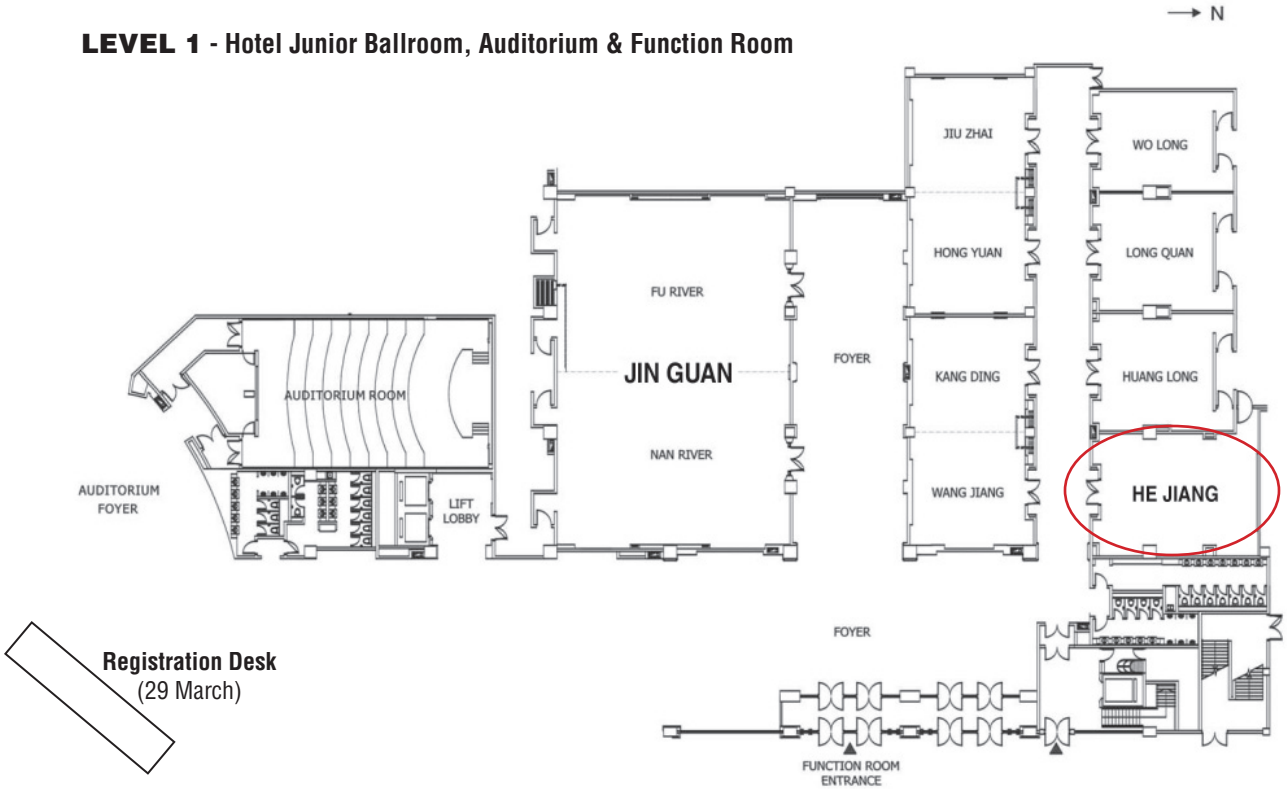
The Shale Gas Technology Forum would like to thank the generous sponsors:

PetroChina SW Co.

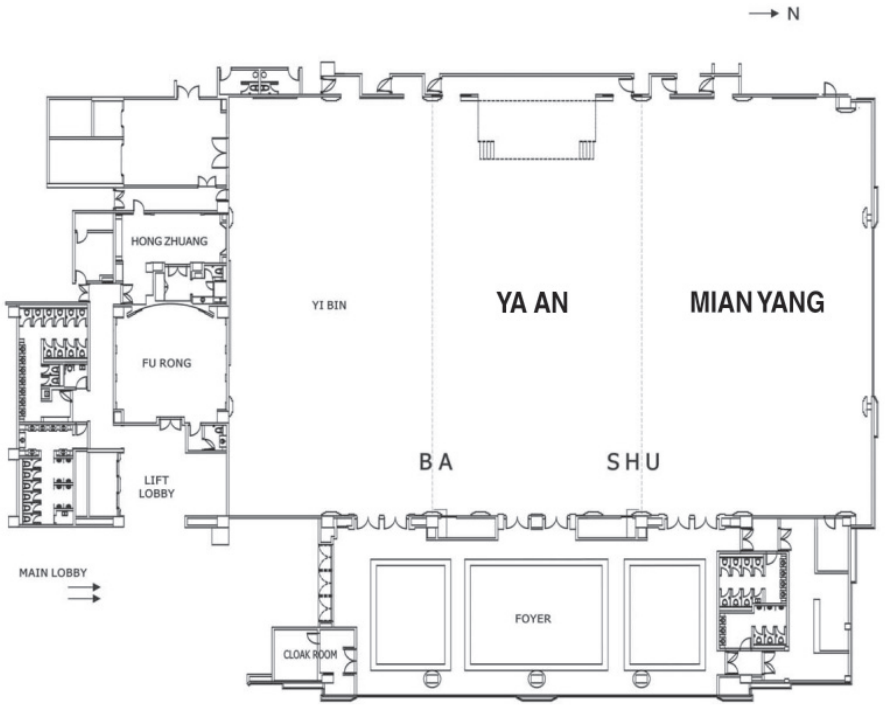
Sichuan Geophysical Co.

HOTEL FLOOR PLAN

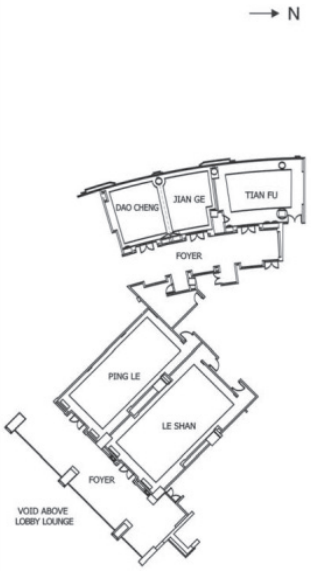
LEVEL 1 - Hotel Junior Ballroom, Auditorium & Function Room



LEVEL 2 - Hotel Grand Ballroom



LEVEL 3 - Hotel Function Room



PROGRAM

Day 1 (29 March)

Registration and Ice Breaker Reception

1–8 p.m. ***Registration*** *(Hotel Second Floor)*
4–5 p.m. ***Session Chair Meeting*** *(He Jiang Room)*
6:30–8:30 p.m. ***Ice Breaker***

Day 2 (30 March) ***Speaker*** ***Affiliation / Presentation Topic***

Session 1: Shale Gas Business & Outlook (Fa Dwan, Jie Zhang, and Alfred Liaw)

8:30 HSE Briefing
8:30–8:50 a.m. ***Klaas Koster*** *SEG / Welcome by SEG President*
8:50–9:10 a.m. ***Wenrong Xu*** *CNPC / CNPC Welcome remarks*
9:10–9:30 a.m. ***Xiyuan Cai*** *Sinopec / Sinopec Shale Gas Projects*
9:30–9:50 a.m. ***Weilin Zhu.*** *CNOOC / Shale Gas Exploration Research*
9:50–10:10 a.m. *Coffee Break*
10:10–10:30 a.m. ***Doug Hazlett*** *Anadarko / North American Shale Plays: Present and Future*
10:30–10:50 a.m. ***Rex Hanson.*** *Chevron / Gas Shale Field Development – Exploration to Operations*
10:50–11:10 a.m. ***Claudia Hackbarth*** *Shell / Shale Gas in China: A new frontier for successful cooperation*
11:10–11:30 a.m. ***Guozhen Zhang*** *PetroChina / The Development Status and Prospect of Unconventional Gas in China*
12–1 p.m. *Lunch*

Session 2: Geology and Rock Physics of Shale Reservoirs (Arthur Cheng and Guozhen Zhang)

1–1:25 p.m. ***Murray Roth*** *Transform Software and Services, Inc. / North American Shale Reservoirs - Similar, yet so different...*
1:25–1:50 p.m. ***Shujing Bao*** *Research Institute of Petroleum Exploration & Production, Sinopec / Reservoir Conditions and Exploration Foreground for Shale Gas in Southern China*
1:50–2:15 p.m. ***Jiajie (Jeff) Chen*** *Marathon Oil Corp. / Challenges beyond Statistical Approach: Integrated Geological Solutions for Shale Plays*
2:15–2:40 p.m. ***Xiang Chen, Yongxin Yan, Xinwen Zhang, Hongtao Liu, Xi Luo***
Henan oilfield of Sinopec / Research on Continental Shale Gas Forming Conditions of Hetaoyuan Formation in Biyang Depression, Nanxiang basin
2:40–3 p.m. *Coffee Break*
3–3:25 p.m. ***Arthur Cheng*** *Halliburton / Rock Physics Modeling of Shale Reservoirs*
3:25–3:50 p.m. ***Amie Lucier, Ronny Hofmann, & L. Taras Bryndzia****
Shell / Static and Dynamic Geomechanical Rock Properties Models for the Haynesville Shale Gas Play, NW Louisiana
3:50–4:15 p.m. ***Xiaoming Tang*** *Chinese University of Petroleum / Sweet Spots of Shale Gas Reservoirs from Borehole Acoustic Measurements*
4:15–4:40 p.m. ***Yaping Zhu*, Alex Martinez, Enru Liu, Michael A. Payne, Christopher E. Harris***
ExxonMobil Upstream Research Company / Geophysical Attribute Analysis of Shale Gas
4:40–5:05 p.m. ***Linye Zhang*, Juyuan Li, Zheng Li, Rifang Zhu.***
Geological Science Research Institute, Shengli Oilfield Company, SINOPEC / Study on the Paleogene Lacustrine Shale Gas in Dongying Depression
5:05–6 p.m. *Panel Discussion*
6:30–8:30 p.m. *Dinner Banquet*

Day 3 (31 March) *Speaker* *Affiliation / Presentation Topic*

Session 3: Geophysics Techniques for Shale Reservoirs (Shouli Qu and Galen Treadgold)

8:30–8:55 a.m. ***Luping Guan, Jia Wei, Quanshi Guo, Da Guan, Zhonggao Ma, Beibei Zhu****
SINOPEC Geophysical Research Institute, Nanjing Geophysical Techniques for Coalbed Methane Exploration and Production

8:55–9:20 a.m. ***Galen Treadgold*, Bruce Campbell and Bill McLain***
Global Geophysical / Application of Seismic Attributes for the Eagle Ford Rock Properties

9:20–9:45 a.m. ***Zheng-Zheng (Joe) Zhou*, Mark Wallace, and John Tinnin***
ION/GXT / Unconventional Role of 3D P-wave Seismic Data in Shale Plays

9:45–10 a.m. *Coffee Break*

10–10:25 a.m. ***Ron Harris and John Tinnin***
Anadarko/ION/GXT...North America case study demonstrating the value of 3D3C seismic for the estimation of shale rock properties.

10:25–10:50 a.m. ***Feng Zhang, Xiang-Yang Li* and Yanghua Wang***
Edinburgh Anisotropy Project, British Geological Survey, China University of Petroleum, Imperial College London, PP- and PS-wave joint inversion in the ray parameter domain for elastic parameters of shale/sand formations from Southwest China

10:50–11:15 a.m. ***Chichu Xie*** *Geophysical Research Institute Of Jianghan Oilfield Branch The Seismic Prediction of Shallow Gas Exploration Targets in Jiannan Area*

11:15–11:40 a.m. ***Kyle T. Lewallen, Michael Matheney*, Rishi Bansal, Kaushik Bandyopadhyay, Andrew Shatilo, John Hefti, Matthew Sabisky, Cyril Rochette***
ExxonMobil / Characterizing an Unconventional Tight Gas Reservoir Using a High-effort 3D 3C Surface Seismic Survey in Northern Piceance Basin, Colorado

12–1 p.m. *Lunch*

Session 4: Drilling, Fracturing, & Resource Assessment (Randy LaFollette and Ziqiong Zheng)

1–1:25 p.m. ***Po Hu*** *Baker Hughes / Advanced BHA Modeling and Drilling & Evaluation Technology to Improve Efficiency in Shale Gas Horizontal Drilling*

1:25–1:50 p.m. ***Jim McRae*** *Anadarko / Horizontal Drilling in North America Shale Gas Plays*

1:50–2:15 p.m. ***Randy LaFollette*** *Baker Hughes / Completions in Horizontal Gas Shale Wells - Setting up for a successful hydraulic fracture treatment*

2:15–2:40 p.m. ***Jack Farmer and Aaron Burton***
Baker Hughes / Completions used to Optimize Shale Gas Fracturing and Production

2:40–3 p.m. *Coffee Break*

3–3:25 p.m. ***PK Pande*** *Anadarko / Shale Gas Assessment - Full Life-cycle Integrated Approach*

3:25–3:50 p.m. ***Tengfei Wang*** *PetroChina / New Developments of Shale Gas Hydraulic Fracturing Technique*

3:50–4:15 p.m. ***Fei Yao*** *PetroChina / The Key Technology to Develop Unconventional Gas-Staging Fracturing Technology in Horizontal Well*

4:15–4:40 p.m. ***Vikram Sen*, A. (Tony) Settari, Bob Bachman & Dale Walters***
Tauraus Reservoir Solutions / Integrated Modeling of Hydraulic Fracture Stimulation and Permeability Enhancement in Shale Reservoirs

4:40–5:05 p.m. ***David Castillo and See Hong Ong****
GeoMechanics Int'l. / Geomechanics Issues in Drilling and Completions and Fracturing Design

5:30 p.m. *Buses Depart*

6:30–9 p.m. *PetroChina Cultural Night (Shunxing Ancient Teahouse)*

◗ ***Day 4*** (1 April)	***Speaker***	***Affiliation / Presentation Topic***

Session 5: Microseismics for Fracture Monitoring & In-situ Stress Estimation (Jin Yu and Kevin Fisher)

8:30–8:55 a.m.	***Mark Zoback***	*Stanford University / Geomechanics and Shale Gas Development: Relationships Among Microearthquakes. Fault Slip and Permeability Enhancements During Slickwater Hydraulic Fracturing.*
8:55–9:20 a.m.	***Kevin Fisher.***	*Pinnacle / Hydraulic Fracture Optimization in Unconventional Reservoirs*
9:20–9:45 a.m.	***Anca Rosca, Sudipta Sarkar, Andrew Jupe, Julie Shemeta, and Robert Langan****	*Chevron / Uncertainty in Microseismic Event Source Parameters Associated with a Fracture Stimulation in a Tight Sand When Using Two Borehole Geophone Arrays*
9:45–10 a.m.	*Coffee Break*	
10–10:25 a.m.	***Michael C. Mueller***	*MicroSeismic, Inc. / Fracture Monitoring by Surface and Downhole Microseismic Recording*
10:25–10:50	***Ron Schmid***	*CGGVeritas / Estimating Stress from Seismic with Applications to Unconventional Reservoirs*
10:50–11:15	***Jiaojun Rong***	*BGP / The Application of Microseismic Monitoring Technique in West China Oilfield*
11:15–11:40	***Bud Pope and Robert Brook***	*Spatial Energy / Remote Sensing Applications throughout the Shale Development Cycle*
12–1 p.m.	*Lunch*	

Session 6: In-situ Stress & Rock Properties (Mark Richardson and Shoujun Wang)

1–1:25 p.m.	***Jon Downton*, Benjamin Roure, & Richard Bale**	*CGGVeritas / Shale Gas Anisotropy Prediction for Rock Properties using Compressional and Shear Wave Seismic Data*
1:25– 1:50 p.m.	***Peter Mesdag***	*Fugro-Jason / Rock Properties from Seismic in Unconventional Shale Gas Reservoirs*
1:50–2:15 p.m.	***Duane Dopkin & Song ChangQing***	*Paradigm / Making Surface Seismic Data More Relevant for Gas-shale Plays*
2:15-2:40 p.m.	***Haikuan Nie***	*Research Institute of Petroleum Exploration & Production, Sinopec / Study on the Shale Gas Accumulation Conditions and Gas Content Calculation-Taking the Lower Paleozoic in Sichuan Basin and its Periphery as an Example*
2:40–3 p.m.	Coffee Break	
3–3:25 p.m.	***Qun Wu & Jian-Qing Li***	*East Company China, SINOPEC / Analysis on Shale Gas Accumulation Conditions in Qianzhong Uplift and Its Periphery*
3:25–3:50 p.m.	***Honglin Liu, Hongyan Wang, Renhe Liu, Gang Yan, and Xiaobo Li***	*PetroChina / Shale Gas Key Experiment and Geological Evaluating Technology*
3:50–4:15 p.m.	***Renjun Wen***	Geomodeling Technology Corp. Fracture Modeling in Shale Gas Plays – A New Method to Integrate *Micro-Seismic and 3-D Seismic Attributes*
4:15 p.m.	*Forum Adjourns*	

Abstracts & Author Biographies

Wednesday, 30 March

Session 1: Shale Gas Business & Outlook

North American Shale Plays: Present and Future

Douglas P. Hazlett

Douglas P. Hazlett, Anadarko Petroleum Corporation

Shale plays have transformed the energy resource base of North America. Published estimates of the resource ranges for natural gas from shale alone, range to over 0.8 QCF (2.2 x 1010 m3). This equates to over 35 years of U.S. current natural gas usage of 22 TCF per year and, when combined with other natural gas resources, equates to 100+ years of energy for the United States. The shale gas resource also creates an opportunity for strong environmental action by decreasing reliance on high carbon fuels such as coal.

The shale plays identified to date in North America predominantly lie within the Paleozoic basins of the eastern and mid-continent portions of the continent along with the Mesozoic foreland basins of the Rocky Mountains. Natural gas is the dominant resource type but several significant liquid-rich plays are developing as well. The largest potential plays include the Marcellus, Horn River, Monterey, Eagle Ford, Niobrara and Haynesville. Many of these "shales" have gross similarities but differ in details such as mineralogical content, porosity, permeability, maturity, depth, brittleness, clay content, etc. Hence, creating innovative and individualized strategies designed for each play in order to efficiently commercialize and recover the huge potential resource is paramount.

Creative technologies and ideas, along with market pricing signals, have played a vital role in making shale gas resources commercially viable. Enabling technologies include horizontal drilling and continuous cost improvements, multi-stage fracs of up to 30+ stages, multi-well pad drilling and 3D seismic. Future technology, efficiency improvements and technology breakthroughs will likely play a large part in expanding this resource even further in North America along with newly emerging shale plays in China, Europe, and Africa. Challenges include managing water resources, surface disturbance, regulatory issues and political environments along with availability of fit-for-purpose rigs, frac equipment and skilled personnel.

Mr. Hazlett has more than 25 years of experience in the oil and natural gas industry. He joined Anadarko in 1984, and has held positions of increasing responsibility within International and domestic exploration including Chief Geoscientist and Manager, US Onshore Exploration. Mr. Hazlett currently serves as Vice President, Exploration, Onshore North America, and his responsibilities include exploration in multiple shale plays including the Marcellus and Eagleford plays. Mr. Hazlett holds a Bachelor of Science degree in geology from Virginia Tech, and a Master of Science degree in geology from Colorado School of Mines. He is a member of AAPG, Rocky Mountain Association of Geologists and Houston Geological Society.

Successful Shale Gas Projects—From Exploration to Operations

Rex Hanson

Rex Hanson, Chevron Asia South Business Unit

Like many other energy companies, Chevron has recognized the shale gas revolution and its impact on the US energy market. We see significant potential for additional shale gas development in China and many other parts of the world. Our current projects are located in the USA, Canada, Poland, and Romania and range from frontier exploration to established production. Though each shale formation has its unique characteristics and productive potential, applying lessons learned from US gas shale development projects and applying manufacturing principles to drilling and stimulation programs can ensure exploration success and provide a low cost, abundant energy source for years to come.

The success of our unconventional projects have been realized by applying project management principles, integrating appropriate technology and a relentless focus on efficiency and cost reduction. Chevrons' five phase Project Management Process is applied to identify risk, manage uncertainty and ensure that the appropriate technical and commercial work are completed for each phase, from Exploration through Operations.

Another critical success factor is application of technology in sub-surface evaluation (outcrop studies, geostatistical modeling, fracture monitoring, and reservoir simulation), project planning and design (fit for purpose rig designs for pad drilling, implementing a factory model manufacturing process for drilling and stimulation).

In one of our US unconventional projects, through the combination of project management principles and appropriate technology we were able to reduce drilling time from 16 days in the delineation phase, to 5 days in the development phase, with a cost reduction of $500 K per well. In the completion process, our teams were able to complete 22 wells, with 129 pumped stages in only 20 days, with day light operations. These efficiencies are critical to project success, enabling the project to maintain competitiveness within a broad band of gas prices.

Examples of exploration screening criteria, technology, the manufacturing process model and successful innovation to reduce costs will be presented.

Rex Hanson is New Ventures Manager within the Exploration & New Ventures Department of Chevron's Asia South Business Unit. Based in Bangkok, he has responsibilities for exploration work and new opportunities in Bangladesh, onshore China, and Vietnam. Rex received his Bachelors and Masters degrees in Physics and Geophysics from Stanford University in 1982. He joined Chevron in 1982 and has held various technical, advisory and management positions in the United States, Sudan, New Guinea, Congo, Kazakhstan, United Kingdom, Nigeria, Vietnam and Thailand during his Chevron career".

Shale Gas in China—A New Frontier for Successful Cooperation


Claudia J. Hackbarth

Claudia J. Hackbarth, Shell China Exploration and Production Company

The Peoples Republic of China (PRC) has set ambitious targets to increase its domestic supply of clean-burning natural gas. Shale gas is one of the hottest exploration concepts in the global E&P industry, and according to 2010 press releases:

- The PRC Ministry of Land and Resources (MLR) set a target for the country to identify 50-80 shale gas prospects and 20-30 exploration and development blocks by 2020.
- The Strategic Research Centre for Oil and Gas of MLR also set a goal to locate one trillion cubic metres of recoverable shale gas reserves, build 15-30 billion cubic metres of production capacity and produce 8-12 percent of China's natural gas from shale gas wells by 2020.

In shale gas exploration, there are two over-arching questions: "Is there a material amount of gas?" and if yes, "Can it be produced economically?". The volume of shale gas resource in place in China is still being quantified, however the global consensus is that the resource base is likely very large. The second question, determination of commerciality, is only beginning to be addressed. Compared to conventional oil and gas reservoirs, shale gas exploration and appraisal projects typically require many wells to first prove the existence of the gas, and then to test and optimize engineering techniques until a commercially viable combination is found. Therefore, the project management roadmap, ways of working, and key decisions may look quite different for a shale project compared to more familiar petroleum exploration projects.

A look-back at existing shale gas developments shows the importance of establishing "learning curves" to support project management decisions. Over time and with experience, improvements in well costs and well productivity give confidence that a full-scale development can achieve economic viability. In North America, government-mandated data sharing as well as voluntary data trades and consortia have greatly accelerated learning. Appropriate collaboration between adjacent projects may also help to optimize major infrastructure investments and mitigate the social and environmental impacts in a full-scale success scenario, enhancing project viability and social acceptability.

Claudia J. Hackbarth was born in Chicago, USA. She received her BA in Chemistry and Environmental Sciences from the University of Virginia, and MS and PhD degrees in Economic Geology from Harvard University. During her 25 years with Shell Oil Company she has held a variety of positions, primarily focused on geological research, innovation, novel technologies, and exploration for unconventional resources. She is currently leading Shell's exploration for shale gas in the Sichuan Basin with partner PetroChina. Her previous assignment was leading Shell's USA shale gas maturation team, which recently delivered to development a successful exploratory program in the Haynesville shale, Gulf Coast Basin.

The Development Status and Prospect of Unconventional Gas in China


Guozhen Zhang

Guozhen Zhang, PetroChina

In this paper, the main features of China's unconventional gas, developmental status and main technology are summarized, and the next steps are proposed. China's unconventional gas reserves is almost the same as that of U.S.A. comparing to U.S.A, China's unconventional gas proven up ratio is very low, and not being developed in large scale, with its production being only 5% of U.S. The main characteristics of China's unconventional gas: reservoir formed near or in source rock; large continuous hydrocarbon accumulation; very tight pay zone; Genesis and occurrence mode varied; very low natural production. To well develop china's unconventional gas, following works need to be done: establishing unified standards, evaluating unconventional natural gas resources distribution, selecting unconventional natural gas enrichment favorable zone, carrying out the following technology research: unconventional natural gas high quality reservoirs seismic logging identification technology; tight gas vertical multilayer fracturing technology; CBM pinnate horizontal well drilling technology, Shale gas horizontal staging fracturing technology.

Zhang Guozhen is a senior geophysicist working for PetroChina for more than 25 years. In 1983-2000, he was general manager of Xinjiang Geophysical Company, in 2001-2005 he was VP of Xinjiang Petroleum Company, in 2007-2010, he was VP of PetroChina E&P Company. Now he is deputy general director of R&D Department of CNPC.

He received his BSc from China Petroleum University for geophysics in 1983 and MBA from the University of Calgary Canada in 2005. He is a member of SEG, AAPG and CPS.

Session 2: Geology and Rock Physics of Shale Reservoirs

North American Shale Reservoirs– Similar, yet so different...


Murry Roth

Murray Roth, Transform Software and Services, Littleton, Colorado, USA

Recent estimates of recoverable gas from unconventional shale reservoirs in the US exceed .5 Qcf (quadrillion cubic feet) (USGS 2009) with potential for another .1 Qcf in Canada (NEB). Large amounts of oil and natural gas liquids further enhance the appeal of unconventional shale reservoirs. While broadly distributed, North American shale oil and gas basins generally follow a trend of thrust belts and a Mississippian/Devonian shale fairway from Western Canada and into the Western, Southern and Eastern United States. The Laramide Thrust Belt bounds the Horn River and Montney Play in British Columbia and Alberta, as well as many of the Western US shale oil and gas resources, including the Niobrara play. Starting in South Texas, the Ouachita Thrust Belt bounds Southern US oil and gas basins including: Eagle Ford, Barnett, Woodford, Haynesville and Fayetteville. Finally, the merger of the Ouachita and Appalachian Thrust Belts define the broad extents of the Marcellus shale gas basin.

North American shale gas reservoirs currently rank as 6 of the largest 22 global gas fields, based upon estimated recoverable reserves, with average recovery factors of about 20%. Innovations in horizontal well drilling and completions, supported by 3D seismic, microseismic, FMI/FMS and other measurements, are unlocking North American gas supplies for the decades ahead. However, volatile commodity markets and dramatic variability in well production rates make economic shale gas production a challenge, driving the current trend to develop the "wet gas" and oil-bearing legs of unconventional shale plays.

With a motivation to understand why "all shales reservoirs are not created equal" - this study integrates published data, type logs, accessible seismic and microseismic data along with 5 years of experience across most significant North American shale basins. Our tabulation of shale reservoir characteristics and well log analysis highlights key production differentiators including depth, thickness, porosity, pressure and TOC. While basins and reservoir characteristics clearly vary - this does not explain significant well-to-well production variations. Part of this variability in production performance is related to evolutionary and company-to-company differences in fracturing "best practices". Surprisingly, after nearly 30 years of development and over 10,000 wells, wellbore lengths and completions parameters in the Barnett Shale of Texas can vary by factors of two or more - pointing to the challenge and non-uniqueness of production optimization.

It is our work with 3D seismic and microseismic, however, that clearly supports the concept of shale oil and gas "sweet-spot" fairways and converse "dead zones". Whether it is faulting in the Woodford, karst collapse chimneys in the Barnett, natural fracturing in the Marcellus or clay/silica content in many plays - seismic and microseismic data provide valuable calibration and prediction tools for mapping productive/non-productive fairways. Multiple data examples from key North American shale plays will be used to illustrate the unique characteristics of the most and least prolific oil and gas producing regions.

Murray Roth is President and co-founder of Transform Software and Services, Inc., the E&P technology company specializing in unconventional interpretation. Over the past 6 years, Murray has worked on projects from a number of unconventional oil and gas plays spanning the United States and Canada. Prior to launching Transform, Murray was Executive Vice President of both R&D and global marketing at Landmark Graphics. After receiving a degree in Astrophysics from the University of Calgary, Murray started his career with Geophysical Service Inc. in 1980, before joining Landmark through Calgary-based IT&A. Murray is a member of AAPG, APEGGA, SEG, EAGE, DGS, RMAG and SPE.

Reservoir Conditions and Exploration Foreground for Shale Gas in Southern China


Shujing Bao

Shujing Bao, Research Institute of Petroleum Exploration & Production, Sinopec

Multiple source rocks have developed in South china, mainly are marine shale of Lower Cambrian and Lower Silurian, transitional facies shale of upper Permian, and lacustrine shale of Upper Triassic-Lower Jurassic. The shale was formed in deep water, half deep water or swamp environment, have good conditions for shale gas development and have been seen good shale gas shows. The marine shale mainly paleozoic distributed in South and western China, sapropel kerogen type, with large distribution area, high abundance of organic matter, old stratigraphic age, high thermal maturity characteristics et al. The continental shale mainly Mesozoic distributed in South China, Northeast China, Ordos Basin and Paleogene of China Eastern, sapropel kerogen type and distribution in the oil-rich depression, with an area of relatively limited distribution, stratigraphic thick and newer, low thermal maturity characteristics et al. The organic matter of lacustrine shale are plankton and higher terrigenous plants, with relatively limited distribution area, high stratigraphic thickness, newer stratigraphic age and lower thermal maturity et al. The paper use shale thickness, total organic content, thermal maturity and other parameters, application of integrated information overlay analysis to forecast the most favorable areas of shale gas development, and provide an important basis for shale gas exploration in south China. The Lower Cambrian and Lower Silurian of Upper and Middle Yangtze region, the Lower Cambrian and Upper Permian of Lower Yangtze region and the Upper Permian and Upper Triassic-Lower Jurassic of the Sichuan Basin and its northeastern margin are the most favorable areas of shale gas development.

Shujing Bao is professorial senior engineer and assistant manager of unconventional energy and technology department. Bao mainly engages in research on sedimentary facies, evaluate of oil and gas resource and evaluate of unconventional oil and gas resource. He earned a B.S. degree from the China University of Geosciences (Beijing), M.S. degree from China Univ. of Petroleum (Beijing).

Email: baosj@pepris.com.

Research Institute of Petroleum Exploration & Production, Sinopec. No. 31 Xueyuan Road, Haidian District, Beijing, China, Post Code: 100083.

Challenges beyond Statistical Approach: Integrated Geological Solutions for Shale Plays


Jeff Chen

Jeff Chen, Marathon Oil Corporation

Doubtlessly, the vast oil and gas reserve contained in shale plays as a new energy form is attracting to operators of various sizes worldwide. However, success in development of these unconventional plays is not guaranteed. Each of the shale play is unique. Therefore, not a single concept or model will fit all. Due to the difficulties of characterizing the shale plays, development in the North American shale basins and other parts of the world is not necessarily optimized. Intense competition and steep learning curve, as well as the outlook for natural gas prices, also make shale play development a major challenge to the industry.

Can optimized geological solutions help enhance the business results of shale play development? This paper provides an integrated approach on

this regard. First, to understand the availability of hydrocarbon source, regional studies and basin modeling must be conducted to understand the maturity of shale plays and their fluid types, and to delineate any possible fairway distribution. Second, seismic data shall be applied to define the reservoir framework, just like the same studies conducted in conventional reservoirs. Third, using new technologies available, facies analysis shall be performed by integrating core and log data. This method can also be applied to deepwater and oil sand reservoirs. Further, quantitative fracture description from core may help understanding fluid conductivity within the extremely tight matrix. Finally, geological description must involve ultra-micro scale to understand the critical details in the shale samples, which provides invaluable information regarding the storages and moving of fluids within the extremely micro pore spaces in shale plays.

Jiajie (Jeff) Chen is an advanced senior geologist with Marathon Oil Company since 2001. He worked for Core Lab (1997-2001) and Amoco Production Company (1993-1997). Jeff obtained his B.S. and M.S. from Zhongshan University in 1981 and 1984 respectively, and served as an assistant professor there from 1984 to 1988. He obtained his Ph.D. from Brown University in 1994. In his technical career, he has conducted research and reservoir studies covering various play types and depositional settings, and different areas including USA, Canada, Mexico, Russia, Venezuela, Colombia, Angola, Gabon, Saudi Arabia, and United Arabia Emirates.

Research on Continental Shale Gas Forming Conditions of Hetaoyuan Formation in Biyang Depression, Nanxiang basin

Xiang Chen, Yongxin Yan, Xinwen Zhang, Hongtao Liu, Xi Luo

Henan oilfield of Sinopec, Nanyang Henan, 473132

Xiang Chen

The Biyang depression of Nanxiang basin is a typical oil- rich depression. It is a tertiary faulted basin which develops on Mesozoic Cenozoic basement and its area is 1000 km2. Shale is mainly distributed in Hetaoyuan 2 and the upper 3 formation in the deep region where is also the hydrocarbon generation center. The total area of shale is about 400km2, Shale gas exploration prospect is bright and it is favorable for shale gas forming. The forming conditions of shale gas of Hetaoyuan formation in Biyang Depression which is the Chinese continental fault basin have been studied based on the U.S. marine unconventional shale gas evaluation index systematically for the first time.13

The favored forming conditions of Shale gas in Biyang depression are listed as follows:

1. Shale extends widely with a large thickness in Biyang depression, the maximum vertical gross thickness is 620 meters, the maximum thickness of a single layer is 100 meters;
2. Total content of organic carbon (TOC) is high for the average TOC 2.52% and suitable thermal evolution degree, the main organic material is I and II a; the general Thermal maturity (Ro) is 0.71%~1.08%;
3. a large amount of brittle minerals such as quartz ,carbonate rock and feldspar is 69.4%~73.5%, clay content 27.5%~30%;
4. The responses of gas bearing shale in well logging are obvious, for example, high Gamma, high Ac, high CNL and low DEN ;
5. Gas content of shale is high for the average absorbed gas of shale is 2.07m3/t in spot test, total gas content is 2.0~5.3 m3/t and average content is 3.3 m3/t through ECS well log;
6. Micro-fracture and micro-pore in shale are responsible for good reserving capacity ,the matrix porosity is 6.67% ,permeability about 0.000227md;
7. the reservoir of shale gas is protected well for less faults and structure event.

Compared with the U.S major shale gas bearing basin, we found that the evaluated indexes such as the (Total organic carbon) TOC, (Thermal maturity) Ro, Shale thickness, brittle mineral content, gas content and the preservation conditions in Biyang depression are similar to that of U.S.A. All of this demonstrated that the Deep region of Biyang depression is beneficial for shale gas forming and there are abound shale gas resource and bright exploration prospect.

Keywords: Continental shale gas; unconventional natural gas; forming conditions; Hetaoyuan formation; Biyang depression; Nanxiang basin

Chen xiang (1962-) Male; Doctor; professor and senior engineer, mainly engaged in oil-gas geology and exploration and management. E-mail:chenxiang123@vip.sina.com

Rock Physics Modeling of Shale Reservoirs

Arthur Cheng, Halliburton

Arthur Cheng

The rock physics properties of shale gas reservoirs are significantly different from those of conventional clastic reservoirs. Because shale reservoirs are highly anisotropic, rock physics models commonly used in sandstone reservoirs are inadequate for describing the elastic and other properties of shales. The anisotropy observed in the shale properties arises from several sources, including the deposition history and environment, maturity of the hydrocarbon, and aligned cracks and grains. This paper reviews the effects on the anisotropic elastic properties of shale reservoirs of each of these parameters, and presents rock physics models to demonstrate these effects. Specifically, using log and core data, this paper demonstrates how various parameters in these models can be constrained. It also shows how other parameters that are necessary, but not directly measurable, can be predicted from logs. For example, using acoustic dipole and Stoneley wave logs, the shear wave anisotropy of the shale reservoir can be estimated. By using the appropriate model parameters, which are obtainable from core measurements, we can also build a rock model that will help to estimate the compressional wave anisotropy.

Arthur C. H. Cheng is the Chief Scientific Advisor for Acoustics and Borehole Seismics at Halliburton. He received a B.Sc. with Distinction in Engineering Physics from Cornell University in 1973, and a Sc.D. in Geophysics from MIT in 1978. He was one of the co-founders of the Earth Resources Laboratory at MIT in 1982, and was Project Leader of the MIT Borehole Acoustics and Logging Consortium until 1996, when he joined Western Atlas. He has also worked for Baker Hughes Inteq, OHM Rock Solid Images, as well as consulting for various companies.

Arthur has served on a number of academic and industry positions through the years; he is currently an Associate Editor for Geophysics in Borehole Geophysics and Rock Properties, and a member of the Advisory Committee for the SEG Beijing Office. Previously he was the Vice President of the SEG Executive Committee, (2009-2010), Chair of the SEAM Board of Directors (2008-9); Chair of the SEG Research Committee (2005-6), and a member of the Visiting Committee for the Department of Earth, Atmospheric, and Planetary Sciences at MIT.

Static and Dynamic Geomechanical Rock Properties Models for the Haynesville Shale Gas Play, NW Louisiana

Amie Lucier, Ronny Hofmann and L. Taras Bryndzia, Shell International E&P Houston TX 77025*

Shale gas plays, such as the Magnolia play in NW Louisiana, rely on hydraulic fracture stimulation for economic production. They also require

representative reservoir models to optimize well placement and hydraulic fracture spacing in the wells. Geomechanical properties are key inputs for both fracture and reservoir simulation models. The properties used in these models must effectively integrate sparse lab-scale measurements with log-derived elastic properties and should also account for the context of the model calculations. In recent years, the capabilities of geomechanical modeling have improved substantially. These geomechanical models are used to predict changes in the stress field and to understand the failure modes in and around the reservoir that result from processes such as drilling, reservoir stimulation, hydrocarbon production, and fluid injection for pressure maintenance or enhanced oil recovery. However, the usefulness of these models depends on having representative geomechanical properties to populate the grid cells.

One end member approach for building these models is to make core measurements over the entire interval of interest and use the laboratory derived geomechanical properties to populate the cells. This approach is rarely feasible due to the lack of available core material, limited laboratory facilities, and expense of making the measurements. With the development of sonic tools (the dipole sonic tool in particular), it is possible to measure the in-situ dynamic elastic properties of formations in the subsurface. Therefore, another approach to building geomechanical models is to relate the elastic (dynamic) properties from sonic data to the mechanical (static) properties measured in the laboratory. With this method, the mechanical properties used to populate the cells in the geomechanical model take into account the geological variability measured in the acoustic well logs while honoring the laboratory measurements.

Dynamic to static relationships are empirical and require a substantial amount of laboratory measurements for proper calibration. For this shale gas play, cores from five wells have been used to develop dynamic to static relationships for the Haynesville formation that can be used to tie the static laboratory measurements to log-derived dynamic elastic properties and provide representative input data for hydraulic fracture modeling.

The authors are all members of the Rock Characterization and Modeling team in Exploration R&D at Shell. Amie Lucier is the SME in shale gas petrophysics, Ronny Hofmann is the SME in Fluid Acoustic Properties and L. Taras Bryndzia is the SME for Inorganic Geochemistry. The teams current research interests include mudrock characterization studies, developing rock physics based models in support of exploration and QI and the integration of petrophysical and geomechanical rock properties in unconventional gas plays and their impact on hydraulic fracture stimulation models.

Sweet Spots of Shale Gas Reservoirs from Borehole Acoustic Measurements

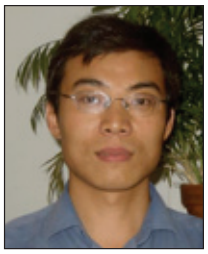
Xiaoming Tang, China Univ. of Petroleum, Qingdao, China

Xiaoming Tang

Gas production in shale gas reservoirs is often found at some sweet spots, i.e., places where large amount of gas is available. Identifying the sweet spots becomes an important issue for shale gas exploration and production. Over the past years, many acoustic log data sets have been collected in shale-gas reservoirs. Analyses of the data reveal that the sweet spots have definite acoustic signatures in the data. These signatures are associated with changes in compressional/shear velocity and shear wave anisotropy in the formation. In many places the signatures are manifested as acoustic wave reflections away from wellbore, allowing the reflectors to be imaged from the reflection data. These acoustic analysis and interpretation results show that the sweet spots are largely associated with fracture network in the reservoir. Thus fracture detection and characterization are key for shale gas reservoirs.

Tang, Xiaoming is professor of Geoscience with China University of Petroleum, Qingdao, China. He worked for Baker Hughes, Inc. from 1994 to 2010 and held the positions of senior scientist, chief acoustic scientist, and Technical Advisor. He received a Doctor of Science degree from the Massachusetts Institute of Technology in 1990, and then worked as a scientist at New England Research before joining Baker Atlas in 1994. His has broad interests in oil & gas exploration including seismic wave theory, borehole geophysics, petrophysics, and rock mechanics. He has authored or co-authored more than 100 technical publications, more than 30 patents/patent applications, and a book on borehole acoustics. He is member of SPWLA, SPE, and SEG.

Geophysical Attribute Analysis of Shale Gas



Yaping Zhu

Yaping Zhu, Alex Martinez, Enru Liu, Michael A. Payne, Christopher E. Harris, ExxonMobil Upstream Research Company*

Unconventional resources such as shale gas are becoming increasingly important exploration, development, and production targets. Although shales share common attributes, such as heterogeneity, low porosity, and low matrix permeability, there are significant differences that make them better sources, seals, or reservoirs. Candidates for economic shale reservoirs require ample organic matter (i.e., relatively high total organic carbon, or TOC) to generate sufficient hydrocarbon volumes and also need to be brittle enough to facilitate hydraulic fracturing.

We studied geophysical responses of shale gas rocks characterized by their organic matter (e.g., kerogen) as a significantly important component of the rock. We hoped this approach would allow us to use log and seismic measurements to predict the elastic and electrical properties, and to characterize TOC. Preliminary studies suggest that the presence of organic matter reduces both P- and S-wave velocities, and hence impedance, while increasing velocity anisotropy. The influence of organic matter on resistivity varies with the level of maturity. As the source rock matures, a portion of the solid organic matter is transformed into hydrocarbons that displace part of the formation water, hence increasing effective resistivities.

The change of effective velocities due to TOC, porosity, and other minerals influences the AVO behavior of shale-gas formations. Silica-rich source rocks typically show a type 2 or 2P AVO pattern, depending on the properties of the background non-source rock, while some clay-rich source rocks show a type 4 AVO pattern. In addition, the AVO behavior depends on the layer thickness and the contrast between the organic-rich intervals and adjacent layers.

Understanding the geophysical responses of shale is an initial and important step toward remote (seismic) characterization of reservoir properties, such as hydrocarbon volumes and fracability. An integrated geophysical study of shale-gas rocks using core/log and seismic data, and with inputs from other disciplines such as sequence stratigraphy and petrophysics, helps to achieve this goal.

Acknowledgments: We are grateful to ExxonMobil for the permission to present this work.

Yaping Zhu graduated from Tsinghua University in Beijing in 2000 and obtained a PhD degree in Geophysics from Colorado School of Mines in 2006. He is currently a geophysicist at ExxonMobil Upstream Research Company.

Study on the Paleogene Lacustrine shale gas in Dongying Depression

Linye Zhang, Juyuan Li, Zheng Li, Rifang Zhu*

Geological Scientific Research Institute, Shengli Oilfield Company, SINOPEC, Dongying, 257015, China

Linye Zhang

The successful exploration of shale gas in North America enlightens Chinese exploration workers. The shale is widely developed in continental basins of East China, and whether there is shale gas resource? This is a new research field in China. With typical significance in East China, Dongying Depression was chosen to analyze the possibility of the existence of shale gas resource in Paleogene lacustrine stratum. Dongying Depression lies in the southeast of Bohai Bay Basin, and it is a third class negative structural element in Bohai Bay Mesozoic-Cenozoic rift basin. The area is 5700km2. The Dongying paleo-lacustrine basin underwent multiple lacustrine transgression and regression cycle, and developed two sets of dark shale during accelerated phase(the late Es4) and peak phase (the early Es3)of evolution. The thickness of dark mudstone of late Es4 is about 250 350m, and the thickness of shale is about 40~120m, with the buried depth is about 1576~5200m. The thickness of dark mudstone of early Es3 is usually above 300m, with the greatest thickness of 500m. The thickness of shale is 150~200m, and the buried depth is about 1500~4200m. According to analysis of geochemical, the shale of lower Es3 and upper Es4 is characterized by high abundance of organic matter, favorable types and wide range of maturity. It has similar geological and geochemical characteristic comparing with North America and the material foundation generating shale gas. The shale in this area has high content of quartz and carbonate and its clay content is less than 50%. In addition, the shale has the characteristic of brittleness and generally developed micro-fractures, which are useful to exploration of shale gas. Under the control of Himalayan Movement, the uplift and erosion of the depression in the end of Dongying Formation (24.6-14Ma), which play an important role in the formation of pore structure and hydrocarbon generation-expulsion of two series shale. The gas logging analysis on the shale of lower Es3 and upper Es4 shows abnormal phenomena; moreover, well kick and leak frequently occurred during well servicing. These phenomena indicate the existence of gas. The abundance of light hydrocarbon (C1-C4) of canned head-space gas of two series shale increase with buried depth increase, and average up to 6.16 m3/t below 3400m. moreover, the ratio of C5-C7 C1-C4 is lower and usually less than 0.15. These indicate that the canned head-space gas of two series shale is dominated by gaseous hydrocarbon below 3400m. Based on above, the study area has potential to form shale gas reservoir and Paleogene Lacustrine shale gas in East China is a new field of natural gas exploration.

Keywords: Dongying Depression; Paleogene; shale gas; organic carbon content; mineral composition

Dr. Linye Zhang, professor senior engineer, major in organic geochemistry. She has engaged in research of the oil and gas geochemistry and petroleum exploration of terrestrial rift basins for many years, and have taken charge and taken part in significant research projects on hydrocarbon generation, oil migration and accumulation of SINOPEC for many times. And now, she is in charge of the resources evaluation research of a National Science Research Project. She is a senior expert of Shengli Oilfield Branch Company of SINOPEC, a group leader of Geochemistry Group and Experiment Technical Group in the Geological Society of China, a director of the Association of Afro-Asian Petroleum Geochemists, an expert with outstanding contribution of Shandong province and SINOPEC, and an expert enjoying the allowance of Chinese government. Correspondence: zhanglinye2006@163.com

Session 3: Geophysics Techniques for Shale Reservoirs

Geophysical Techniques for Coalbed Methane Exploration and Production

*Luping Guan, Jia Wei, Quanshi Guo, Da Guan, Zhonggao Ma, Beibei Zhu**

SINOPEC Geophysical Research Institute, 210014

Luping Guan

1. Introduction

As a type of unconventional oil and gas resource, coalbed methane (CBM) is self-sourced & self-reservoir, and characterized by low abundance and adsorption occurrence. Different from conventional oil and gas, CBM reservoir is continuous with no obvious boundary and hence no trap. Till now, there isn't an economic and effective geophysical technical series for CBM exploration and production.

2. Petrophysical features for coal bed reservoir

Coal bed is strongly anisotropic. Anisotropy parameters vary greatly with coal composition. Coal ash/partings decrease the anisotropic degree. As typical thin layers coal seams have unique reflection features that are different from single impedance contrast boundary. Reflection parameters, such as amplitude, are influenced by impedance contrast as well as the thickness/wavelength ratio. Compared with single boundary reflection, coal bed reflection amplitude shows a 1st order derivative pattern. Reflection energy of coal bed is quite strong. Thus the reflection energy of shallow coal beds causes shielding effect for deep coal layers. Coal bed thickness greatly influences its amplitude and frequency. Due to this tuning effect, AVO feature is affected by not only lithological variation but also thickness. Besides, for coal beds under thin interbedded conditions, variation of reflection patterns is also related with surrounding rocks. Therefore, "bright spot" has multi-solutions and when performing seismic inversion and attribute analysis, same frequency range shall be applied.

3. Seismic techniques for CBM exploration and production

In CBM seismic exploration, full spectrum-band seismic recording shall be adopted, and preserving low frequency signals is the key point in data acquisition. For data processing, static correction is crucial because of low buried depth and variable surface conditions. Thus an appropriate "static focused" processing workflow could be performed. Seismic attributes and data inversion play an important role in three aspects of data interpretation, including coal bed boundary division, internal reservoir characterization and gas-bearing properties prediction. First, based on petrophysical analysis and seismic responses, coal bed thickness prediction and boundary characterization could be achieved by frequency division technique and thin layer tuning effect analysis. Second, fracture system characterization for coal bed reservoir can be performed with post-stack discontinuity detection and curvature technique. Meantime, AVO is also applied to depict fracture system under the direction of seismic anisotropy theory. Finally, AHP (analytic hierarchy process) method combining with EI inversion, post-stack impedance inversion and spectral absorption & attenuation method could provide quantitative characterization for CBM enrichment. Additionally, borehole seismic (mainly VSP) is also helpful in providing more direct information to characterize fractures near borehole.

4. Electromagnetic methods for CBM exploration and production
CBM enrichment is closed related to hydrodynamic conditions. Applying electromagnetic techniques such as CSAMT could help to detect apparent resistivity, divide electricity characteristic layers and judge water-bearing zones and water-rich zones, which finally leads to indirect favorable zones prediction.

5. Conclusions
Surface seismic techniques shall be given priority in CBM exploration and production. While borehole seismic (quasi 3D-VSP and reverse VSP) could assist in anisotropic analysis (fractures detection) for near-well reservoir, providing basic information for well type selection (multi-branch horizontal well or vertical well) and well deployment (vertical well group). Electromagnetic techniques can also be regarded as supplementary means in CBM prospecting.

Guan Luping, male, born in 1964, is a professor of Geophysicist. He received Bachelor of Engineer in geophysics from the Department of Geophysics, Chuangchun Geology College in 1985, and Master of Science from the Department of Computer Science, Fudan University in 1987. Mr. Guan is the vice president of SINOPEC Geophysical Research Institute. He has conducted fruitful researches in several areas of exploration geophysics, such as prediction of cavern-fracture carbonate reservoirs and wave propagation in complex media. He is now working on Geophysical Description of Cavern-Fracture Carbonate Reservoirs, one of the China national "973 Projects", and the Key Techniques for Geophysical Exploration of Coalbed Methane Gas, one of the China national key scientific and technological projects.

Application of Seismic Attributes for Eagle Ford Rock Properties

Galen Treadgold, Bruce Campbell and Bill McLain, Weinman GeoScience/Global Geophysical*

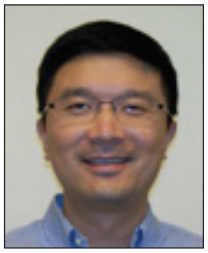
Galen Treadgold

The Eagle Ford Shale in South Texas is one of the more exciting shale plays in the United States at the current time. Recently published reports of well tests describe gas well rates exceeding 17 mmcf/d and oil well rates in excess of 500 bopd and unconfirmed rates of 1500 bopd. Acreage lease rates continue to climb as more positive results come from drilling within the trend. A key issue for the exploration companies is finding where to focus acreage acquisition and optimize drilling plans for optimal gas and oil recovery. Our paper will consider the geophysical tools available to understand and predict shale variability. We will start with a look at current acquisition and processing technology and the focus on anisotropic processing for feeding elastic inversions. Examples of more than 1,000 km2 of newly acquired 3D will be shown with targeted analysis to highlight fractures, porosity and brittle/ductile behavior.

Galen E. Treadgold, vice president of Weinman GeoScience, received a BS in Geology and Marine Science in 1982 from the University of Miami before starting his geophysical studies at the University of Texas at Austin and receiving an MA in Geology/Geophysics in 1985. Galen joined ARCO that same year and over the next 15 years worked in various technology, exploration and management positions including coordinating AVO projects, teaching the first ARCO AVO school, managing the ARCO British technology group and managing ARCO's Trinidad and Venezuela SPG Conference in Hyderabad, India and the 2010 RMAG Conference in Denver. exploration effort. In 2000, Galen joined Weinman Geoscience where he has held the position of chief geophysicist and now, vice president. Galen's main interests are direct hydrocarbon detection technology and azimuthal analysis for fracture detection. He has given recent talks at the 2010 SEG in Denver, the 2008 Unconventional Reservoirs Symposium in Vancouver, the GSH Sherwood Symposium in Houston.

Unconventional Role of 3D P-wave Seismic Data in Shale Plays

Zheng-Zheng (Joe) Zhou, Mark Wallace, ION Geophysical / GX Technology Division*



Zheng-Zheng (Joe) Zhou

Introduction
Shale reservoirs have become important hydrocarbon objectives for oil and gas companies.

Although advances in drilling technology have been the primary factors in achieving economic viability in these tight reservoirs, 3D P-wave seismic data has played an increasingly important role in development success. Initially seismic data was used primarily in a conventional role: hazard avoidance. However, over time, shale operators have realized that seismic data can provide additional value in an "unconventional role": to estimate stress fields, characterize natural fracture systems, and predict reservoir rock properties such as brittleness.

Azimuthal velocity analysis, stress fields, and fractures
Due to their low permeability, economic production in shale reservoirs can only be achieved through hydraulic fracture stimulation. A key factor in economic success is the ability to create as extensive and complex a fracture network as possible. The fracture network is strongly controlled by the in-situ stress field and any natural fracture systems present.

Unequal horizontal stresses and vertical aligned fractures can cause seismic velocities to vary with source-receiver azimuth. Azimuthal velocity analysis allows the measurement of the variation in velocity with azimuth and the determination of azimuthal velocity anisotropy attributes which can provide information about stress fields and natural fracture systems. Because a wide fracture fairway is best achieved under a low differential stress environment, the azimuthal velocity anisotropy attributes may help predict areas most likely to have an optimal stress environment. In addition, when hydraulic stimulation is required to enhance the recovery of naturally fractured reservoirs, the interaction between the stress field and existing natural fractures becomes an important issue. The ability to estimate the density and orientation of natural fractures systems from seismic velocity anisotropy and relate this information to the stress field can help geoscientists identify "sweet spots" in tight, heterogeneous reservoirs.

Seismic inversion and reservoir rock properties
Hydraulic fracture stimulation creates the permeability pathways needed in low permeability reservoirs. Since brittle rock fractures more easily, the ability to identify zones of increased brittleness within shale reservoirs may help operators to optimize the results from fracture stimulation. Optimum shale properties for geo-mechanical brittleness include: relatively high Young's modulus; low lambda (incompressibility); high mu (rigidity); and/or low Poisson's Ratio. These properties may promote the creation of extensive induced fractures during hydraulic stimulation. The ability to estimate reservoir brittleness from seismic data allows the geophysicist to help the completions engineer optimize the hydraulic stimulation design since more brittle zones may require fewer hydraulic fracture stages and/or smaller treatment volumes than less brittle zones. Also, areas with more brittle rock may result in higher well IPs and EURs, as well as, lower drilling densities. Seismic inversion provides a means to estimate these important rock properties from seismic data.

Summary
Stress fields, natural fractures systems, and reservoir rock properties play important roles in the development success of shale reservoirs. New seismic analysis techniques enable geoscientists to estimate stress fields, predict fracture patterns, and estimate reservoir rock properties from 3D P-wave seismic data. This information can help identify sweet spots within tight reservoirs.

Zheng-Zheng (Joe) Zhou studied physics at USTC and Rice University, graduating with a MSc from Rice in 1996. Joe worked at NuTec Energy

Services from 1996 to 2004 in positions ranging from research geophysicist to R&D manager. He was responsible for the development of a seismic processing system and a full range of algorithms including depth imaging tools. In 2004, Joe joined ION Geophysical / GX Technology where he now works as chief geophysicist. At GXT, Joe works on Reverse Time Migration, depth imaging, and multi-component seismic.

North American Case Study Demonstrates the Ability of 3-D/3-C Seismic Data to Predict the Petrophysical Properties of Shale

Ron Harris, Anadarko, John Tinnin, ION Geophysical / GX Technology

Ron Harris

John Tinnin

The Devonian age Marcellus is a major shale play in North America that has drawn international attention. It covers approximately 250,000 square kilometers, trending northeast from West Virginia into New York. The Marcellus is believed to have the potential to become the second largest gas field in the world, with original gas-in-place estimated at nearly 1500 tcf. Commerciality was established in 2004 and the basin now has well over 100 rigs actively drilling. The majority of these wells are drilled as horizontal wells with laterals 1 to 2 kilometers in length. Hydraulic fracturing is required to stimulate a sufficient volume of shale that will produce commercial quantities of natural gas. Within the study area, the Marcellus Shale is approximately 60 meters thick and buried at a depth of 2.6 kilometers.

The challenges of this play include:

1) identifying shale 'sweet spots' which represent areas of higher productivity that are driven by several petrophysical properties including porosity, permeability, brittleness and total organic content (TOC);

2) optimizing well designs and geo-steering through detailed, seismically derived structure maps that identify subsurface features such as fold axis, faulting and collapse associated with salt dissolution;

3) optimizing the stimulation program by understanding the variances in rock properties within the shale zone and the areal distribution of Young's Modulus, Poisson's Ratio, and local stress regimes.

To address these challenges, a 67 square-kilometer, wide-azimuth, multi-component 3-D seismic survey was recorded in central Pennsylvania to determine the effectiveness of modern 3-D/3-C seismic data in extracting certain rock properties from the Marcellus Shale.

In parallel, a rock physics study was conducted on well logs penetrating the Marcellus Shale within the survey area to model the predicted seismic attribute response. Analysis of the modeled attributes provided valuable insight into shale porosity, brittleness, kerogen content, VP/VS and density. Seismic attribute volumes that reflect elastic properties were generated from the seismic data along with geometric attributes of curvature and coherency. Multiple inversion techniques were also investigated, including a P-wave simultaneous inversion and a joint PP/PS inversion to document the value derived from the 3-D/3-C seismic data. All elastic and geometric seismic attribute volumes were calibrated to the existing subsurface data including wireline data, core data, microseismic events and production information for use in 'sweet spot' prediction.

Upon completion of the project, the team concluded 3-D/3-C seismic data were able to predict a set of rock properties from composite inversions and attribute volumes within the Marcellus shale that were validated by well data. By utilizing these multiple attribute volumes and inversion products, 'sweet spots' can be identified to optimize drilling locations and stimulation programs.

Ronald E. Harris received his BSc in Geophysical Engineering from the Colorado School of Mines in 1981. Upon graduation, he accepted a position with Tenneco Oil as an interpreter in Lafayette, Louisiana where he remained until the sale to Chevron in 1988. He then joined Union Oil of California where he worked in the Gulf of Mexico group as a development geophysicist. In 1997, he joined Cockrell Oil and Gas in Houston Texas where he was responsible for property management, well planning, and providing technical support to the Exploration groups. At present, he is a Senior Geophysical Advisor at Anadarko Petroleum Corporation where he is actively involved in the Exploration and Development of the Marcellus Shale in Pennsylvania and mentoring young geoscientists. He is a member of the Society of Exploration Geophysicists and a licensed Professional Geoscientist in the state of Texas.

PP- and PS-wave joint inversion in the ray parameter domain for elastic parameters of shale/sand formations from Southwest China

Feng Zhang and Xiang-Yang Li, Edinburgh Anisotropy Project, British Geological Survey, also at China University of Petroleum, Beijing, Yanghua Wang, Imperial College London*

Xiang-Yang Li

Joint inversion of PP- and PS-wave can be used to determine the elastic properties of shale/ sand formations. However, due to the dual data input and multiple parameters output, there are at least two challenges in such an inverse problem. First, how to appropriately match PP- and PS-waves is a critical problem in the joint inversion. The PS-wave consisting of a down-going P-wave and a converted up-going S-wave propagates along a asymmetrical ray path, which differs with the PP-wave reflection in both the time and space domains. The second challenge is how to balance the sensitivities of different classes of physical parameters to be estimated in the joint inversion.

In this paper, we develop an inversion method to estimate three elastic parameters, P-wave velocity, S-wave velocity and density, simultaneously from the PP- and PS-wave data. We perform the inversion in the ray parameter domain since the ray parameter remains constant for both PP- and PS-waves from the same reflection point. The inversion is applied to a multi-component data set acquired over shale/sand formations with extremely low porosity and permeability in southwest China. The inverted elastic parameters are consistent with the corresponding well logs. The P-wave velocity, S-wave velocity and even the density show stable and accurate results, from which we can interpret the formation properties directly.

Xiang-Yang Li, currently is a senior principal scientist in the British Geological Survey (BGS), and director of the Edinburgh Anisotropy Project, based on the BGS and the University of Edinburgh. He also holds the directorship of the CNPC Geophysical Key Laboratory based on the China University of Petroleum in Beijing. Before that, he held the chair of multi-component seismology in the University of Edinburgh. Professor Li had a BSC in geophysics in 1982 from the Changchun Geological Institute, a MSc in applied geophysics in 1984 from the East Petroleum Institute, and a PhD in seismology in 1991 from the University of Edinburgh. Professor Li is married with two children.

The seismic prediction of shallow gas exploration targets in Jiannan area

Chichu Xie, Geophysical Research Institute Of Jianghan Oilfield Branch

Chichu Xie

There are 3 sets of exploration target shallow layers of different types in Jiannan area, which are sixth member of sandstone of Upper Triassic Xujiahe Formation, the Zhenzhuchong sandstone and shale-argillutite of Dongyuemiao of Lower Jurassic Zhiliujing Formation. To these exploration target, basing on seismic data, the paper combine with drilling and logging data, using different methods to predict reservoir distribution characteristics, and combine with tectonic background, reservoir distribution and the development of fracture, identify lithologic traps, choose optimal exploration target.

The gas reservoir of Upper Triassic Xujiahe Formation xu6 section is a lithologic gas reservoir which is controlled by the development of sandstone reservoirs under the tectonic background. The reservoir prediction method is: based on the analysis of reservoir properties, established seismic geological model, study the characteristics of seismic response by seismic forward model, determine the sensitive parameters of reservoir prediction, choose optimal the technology and methods of reservoir prediction, through seismic attribute analysis predict the favorable distribution of reservoir, and then to predict distribution characteristics of sandstone reservoirs by impedance inversion.

The gas reservoir of Lower Jurassic Zhiliujing Formation Zhenzhucong section is a lithologic gas reservoir which is controlled by fracture, and the fracture development zone is also part of lithologic traps. Basing on sandstone reservoir prediction, we focus on the development part of fracture. Using of seismic coherence, curvature and variance analysis, combined with seismic attribute analysis, forecasting the fracture zone. Predictions indicate that the main fracture zone controlled by faults and tectonic deformation. The fractures are mainly distributed in the tectonic axis, the end turn structure and faulted zone.

Lower Jurassic Zhiliujing Formation Dongyuemiao section are mainly strata of shale gas exploration. The research is focused on prediction of mudstone thickness and fractures. The gas layer of Dongyuemiao section is mainly distributed in strata of mudstone. Forecast method is starting from the drilling data, tracking the seismic profile which shown in under the response characteristics of shale-gas well, and analyzing seismic attribute and impedance inversion at the same time, predicting the thickness distribution of mudstone. With the development of thin sandstone and fractures in the mudstone, we can determine the optimal exploration area.

Chichu Xie, male, born in 1963, senior engineer, Deputy Director of Research of Marine Facies, Geophysical Research Institute of Jianghan Oilfield. Graduated from Daqing Petroleum Institute in 1984, Geophysical Major, Bachelor's degree. Graduated from Tong Ji University in 1997, Marine Geology Major, Master degree. Research interests include seismic interpretation and comprehensive research.

Characterizing an unconventional tight gas reservoir using a high-effort 3D 3C surface seismic survey in northern Piceance Basin, Colorado

Kyle T. Lewallen ExxonMobil Upstream Research Company, Michael Matheney ExxonMobil Upstream Research Company, Rishi Bansal ExxonMobil Upstream Research Company, Kaushik Bandyopadhyay ExxonMobil Upstream Research Company, Andrew Shatilo ExxonMobil Upstream Research Company, John Hefti ExxonMobil Exploration Company, Matthew Sabisky ExxonMobil Production Company, Cyril Rochette ExxonMobil Production Company*

A 3D 3C seismic survey was acquired over the northern Piceance Basin in 2009 to address variable drilling results in the tight sandstone Mesaverde reservoir of the Piceance Creek Field. Previous well log, borehole seismic, and surface seismic work highlighted the potential of using S-waves to complement conventional P-wave seismic data for reservoir characterization. While structural and stratigraphic interpretation are performed on the higher resolution P-wave seismic data, S-wave anisotropy can add valuable information to characterize fractures and predict lithologies. However, relating surface seismic based anisotropy to reservoir properties is complicated by the interaction of lithology, fractures, stress, fluid saturation, and pore pressure on anisotropy. Data from the high-effort multicomponent 3D survey are currently in processing but preliminary volumes show consistency with previous borehole measurements. We anticipate that joint interpretation of final PP and PS volumes can significantly impact the future drilling program in Piceance. Application to other unconventional resources is ongoing, with shale gas and heavy oil fields also showing the potential for improved lithology and fracture characterization using S-wave data.

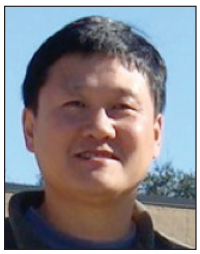
Michael Matheney will be presenting the submitted paper entitled "Characterizing an unconventional tight gas reservoir using a high-effort 3D 3C surface seismic survey in northern Piceance Basin, Colorado".

Mike received a Ph.D. (1997) in geophysics from Purdue University. He worked as an intern at Amoco Research Center, Chevron Technology Center, and Exxon Production Research Company. He joined the exploration organization of Exxon in 1997 and has since worked production, development, and research projects within ExxonMobil. His fields of interest include multicomponent seismic data, seismic inversion, and seismic-based reservoir characterization. He is a member of SEG and AAPG.

Session 4: Drilling, Fracturing, & Resource Assessment

Advanced BHA Modeling and Drilling & Evaluation Technology to Improve Efficiency in Shale Gas Horizontal Drilling

Hu Po, Baker Hughes



Hu Po

Unlike conventional reservoirs, gas shale serves as the source rock, reservoir rock, and seal. Due to its low porosity and permeability, horizontal drilling and extensive hydraulic stimulation are essential to produce economically.

Complex well profiles and extended length laterals are required to maximize productivity. Some of the major drilling challenges that affect drilling efficiency are excessive slide drilling time, difficulty in controlling well trajectory, unacceptably low penetration rates, premature bit damage, and high torque & drag. BHA and drill string modeling with finite element analysis can be used to eliminate buckling and improve transfer of weight to the bit, and to optimize BHA design in order to overcome these challenges.

Wellbore tortuosity and high friction factors in long lateral causes inefficient transfer of weight on bit and reduces rate of penetration (ROP). Existing rotary steerable systems available are typically cost prohibitive for this application/environment. A new automated rib-steering closed-loop system has been developed specifically for 3D well bore's rotary steerable directional drilling in low spread cost land-drilling applications. Such advanced directional drilling technologies can significantly improve drilling performance.

Planning the hydraulic fracturing program requires a precise evaluation of the bedding planes and fracture sets, both natural and induced. In the past, resistivity imaging tools were run on wireline to acquire this information. State-of-the art LWD tools capable of acquiring high resolution resistivity images while drilling at high rate of penetration make it possible to obtain this information in horizontal interval.

BHA and drill string modeling, coupled with advanced directional drilling and LWD tools can significantly improve drilling performance shale gas horizontal drilling.

Hu Po, male, graduated with a B.S. from the Exploration Department, Southwest Petroleum University of China in 1982. After graduation, Mr. Hu joined PetroChina and worked in Karamay and Tarim oil fields for 10 years as well site geologist and mud logging engineer. Mr. Hu joined Baker Hughes in 1993 and worked as mud logging engineer, MWD/LWD engineer, tech support engineer, well planner, drilling application engineer, technical trainer, field test engineer, field test and system integration manager, and technical director of North Asia geomarket. Mr. Hu has been involved in many Baker Hughes drilling and evaluation system R&D projects include rotary steerable drilling system AutoTrak G3, steerable drilling liner, high speed telemetry system, formation evaluation system OnTrak, acoustic measurement SoundTrak, nuclear resonance measurement MagTrak and high definition borehole imaging system StarTrak etc.

Horizontal Drilling in North America shale gas pays

Jim McRae, Anadarko Petroleum Corporation

Jim McRae

Anadarko Petroleum Corporation is a major Operator in several key North American shale gas plays which include Pennsylvania's Marcellus shale, South Texas' Eagleford shale and the Haynesville shale in East Texas. The presentation will give an overview of their drilling operations in these 3 developments along with discussion on learning curves and lessons learned. APC will compare and contrast key engineering criteria such as well designs, mud selection, single wells vs multi-well pad drilling, and directional tool selection/performance.

Jim McRae is a Drilling Operations Manager for Anadarko Petroleum Corporation, based in The Woodlands, Texas. His 26 year career spans engineering and management positions in production, drilling and completion activities in US Onshore, Gulf of Mexico, Australia, and China. Prior to his current duties for APC's Southern Region, Jim worked for 8 years in Beijing China as Kerr McGee China Petroleum Ltd's Manager of Drilling & Completions on the Bohai Bay CFD Development. Jim represented KMCPL as the 2007 recipient of the Tianjin Hai He Friendship Award, which recognized their significant contributions by successfully implementing many new technologies for the CFD Development. CFD currently touts over 110 horizontal wells drilled and completed. Jim holds a BS in Petroleum Engineering from Texas Tech University.

Completions in Horizontal Gas Shale Wells: Setting Up for a Successful Hydraulic Fracture Treatment

Randal F. (Randy) LaFollette, Baker Hughes

Randal F. (Randy) LaFollette

The extremely low matrix permeability of the US gas shales demands three conditions if gas is to be produced from any given shale stage. First, reservoir quality rock must be present. Second, a hydraulic fracturing treatment must be placed and must result in the required fracture geometry and in a conductive connection to the well bore. Third, the fracturing fluid must be adequately cleaned up following treatment. If any of these three items fails, that stage will not produce gas. In short, well performance is dependent on the success of the hydraulic fracturing treatment.

Well architecture, i.e., well azimuth, completed length, and drift angle, combine with stage diversion effectiveness of the completion to set up conditions in which the hydraulic fracturing treatment will succeed or fail. Exhaustive data-mining of production results in US shales has shown that well azimuth, length, drift angle, and completion type can have major impacts on production results. This presentation documents the highlights of a data-mining study of well, completion, hydraulic fracture treatment, and production parameters for horizontal wells in the north Texas Barnett Shale play. The authors have analyzed well and production data from more than 13,400 producing Barnett wells. A sub-sample of over 3,300 horizontal wells was characterized with respect to detailed well architecture data such as drift direction and angle, lateral length, perforations, etc. The study uses Geographical Information System pattern-recognition techniques in conjunction with more traditional statistical techniques to interpret hidden trends in otherwise scattered data sets.

This work shows that the application of practical data-mining methods to a large Shale Gas data set can result in learning key lessons that may not be apparent when working with small data sets. The overall study from which the presentation is derived is also significant in the use of merged reservoir quality proxies, well architecture data, completion data, and stimulation data, against which production results are placed in geographical perspective for improved interpretation.

Randal F. (Randy) LaFollette is the Manager, Shale Gas Technology, for Baker Hughes, located in Tomball, Texas. Mr. LaFollette holds a Bachelor of Science degree in Geological Science from Lehigh University, Bethlehem, Pennsylvania. He has 33 years of experience in the oil industry; including field, region, and research level positions, and has worked for The Western Company of North America, Reservoirs, Incorporated, and BJ Services. He is active in SPE, and other industry organizations, aiding with conference organization and presenting on various reservoir and completion / stimulation topics. He is a co-author of an industry book on hydraulic fracturing, "Modern Fracturing, Enhancing Natural Gas Production." Current job responsibilities include management and coordination of laboratory and applied support projects and data mining studies within Baker Hughes.

rlafollette@bjservices.com

Completions Used to Optimize Shale Gas Fracturing and Production

Jack Farmer

Jack Farmer and Aaron Burton, Baker Hughes

Due to its low porosity and permeability, horizontal drilling and extensive hydraulic stimulation are essential to produce economically. Specialized tools are required to complete horizontal wells and accurately place the fracturing fluids

Open hole completion systems provide a completion method using packers to isolate sections of the wellbore (stages) and frac sleeves to direct the frac treatment to the desired stage. These types of completions are very modular and allow operators the flexibility to customize a completion that best meets the challenge at hand such as rotational capability, acid resistance, or extended stages.

The isolation packers are typically either a fluid activated packer or a hydraulic activated packer. The fluid activated packer can be set using a water-base fluid or a petroleum based fluid. A hydraulic set packer requires a form of wellbore isolation to create a differential pressure between the tubing and annulus of the well to set the packer.

Typically the first frac stage is a pressure activated frac sleeve that allows the operator to regain wellbore communication without thru-tubing intervention. Apply pressure will open the sleeve and the first frac can begin. The remaining frac sleeves contain different size ballseats that can be isolated using a frac ball. .

Jack Farmer, Male. Mr. Farmer went to work for Baker Hughes in Midland Texas 1981 as a field engineer running open hole DST, transferred to Middle East after two years where he was field engineer running open hole DST's, tech support and sales for inflatable products, operations manager and District Manager for completion equipment, SSSV, Liner Hangers, Flow Control, after spending 24 years in Middle East and Asia, went back to Houston as Completion support, BDM for Packers, PLM for packers, Global BDM for Completions and Production and how is PLM for Unconventional Completions.

Shale Gas Assessment—Full Life-cycle Integrated Approach24

P. K. Pande

P. K. Pande, Anadarko Petroleum Corporation

A full life-cycle integrated approach for shale gas plays is an essential tool for value creation, reserves and production growth worldwide. Such an approach allows for key issues and uncertainties in shale gas resource development to be better understood as plays evolve from concept screening, to exploration and resource assessment to full development. As production matures the focus must shift to reservoir management and surveillance; as well as options for field re-evaluation and re-development.

The integrated approach relies upon four key elements:

1. Field Demonstrations;
2. Mechanistic Studies;
3. Performance Analysis; and
4. Integrated Asset Management (IAM).

This presentation outlines the need and benefits of using these cornerstone elements for shale gas assessments and exploitation.

Field Demonstrations: The design, planning, and implementation of systematic and "scalable" Field Demonstrations are essential elements required to address key issues and uncertainties in shale gas plays. Specifically, field demonstrations are designed to address strategic, development and operational issues. Other key elements in the field demonstration implementation include the generation of integrated reservoir descriptions (IRDs), performance analysis using both analytical and numerical techniques, and validation of performance using both static and dynamic data.

Mechanistic Studies: Are utilized to understand the key production drivers. Specific objectives of mechanistic studies include:

1. To understand expected well productivity and resource base estimates;
2. To understand reservoir production mechanisms;
3. To evaluate completions and investigate optimum stimulation techniques;
4. To evaluate multiple shale targets and associated performance; and
5. To investigate well spacing for optimum development.

Performance Analysis: Shale gas productivity is typically much lower than conventional reservoir systems and often lower than "tight gas reservoirs. A combination of low to ultra-low permeability and use of a horizontal well with multiple hydraulic fractures yields a linear flow regime which may dominate production for much of the economic life of wells. The flow regimes which occur in these systems need to be understood in order to effectively characterize and predict performance behavior. The concept of "Continuous EUR" is utilized in these extremely tight reservoirs to provide time-dependent estimates of reserves. In addition, multiple analysis methods are used to provide valuable insight into EUR projections. Both inter- and intra-field analysis are key to optimal full life-cycle project management.

Integrated Asset Management (IAM): Efficient execution and optimization of shale gas plays, which will ultimately require a large number of wells to attain significant production volumes, is a key challenge for the industry. The IAM approach proposes to integrate the entire producing system of subsurface, wells, and surface network — and to introduce appropriate process workflows and processes efficiencies needed effectively exploit shale gas resources.

Summary: Integration, innovation, and collaboration across a wide range of disciplines are central themes in this presentation needed to attain commercial goals in fast paced shale resource development.

P.K. Pande serves as Director, Reservoir Technology with Anadarko Petroleum Corporation, the world's largest independent E&P Company. His responsibilities include managing an integrated team of subsurface

professionals including geologists, geophysicists and reservoir engineers in application of technologies and best practices encompassing reservoir management and surveillance, reservoir development and new field early appraisal for Anadarko's international and domestic operations. He leads the Reservoir Technology team for shale resource assessments and development. He has also served as Subsurface Manager, Ourhoud Field, Algeria, the country's second largest oil-field.

Mr. Pande has contributed to the development and reservoir management of numerous world class reservoirs including Prudhoe Bay (North America's largest oil field) and Endicott (the first arctic offshore oilfield). He was instrumental in the design, planning and implementation of the Prudhoe Bay Miscible Gas Project, the largest enhanced oil recovery project in the world. He served as Project Manager for U.S. Department of Energy's flagship project on improved recovery and reservoir characterization methods for shallow shelf carbonate reservoirs. Mr. Pande holds a B.S. degree in Chemical Engineering from the University of California at Berkeley, and a M.S. degree in Petroleum Engineering from the New Mexico Institute of Mining and Technology.

New Developments of Shale Gas Hydraulic Fracturing Technique

Tengfei Wang

Tengfei Wang, PetroChina

The shale gas in the United States has been developed rapidly in recent years, and the annual production of shale gas was only about 12.2 billion cubic meters in 2000, while in 2009 it reached about 87.8 billion cubic meters, the rapid development of shale gas was attributed to the development of hydraulic fracturing technique. A large number of field tests in North America showed that the greater the stimulated reservoir volume (SRV) was, the more the production increased, so how to maximize the SRV was considered as the key to shale gas hydraulic fracturing since 2007. Through data analysis, experimental evaluation and field tests, find that the SRV depends on two aspects: the first one is the characteristics of the reservoir itself, such as the horizontal stress difference, natural fractures, beddings, and brittleness, etc; the second one is the construction control, such as perforation cluster spacing, shooting numbers, liquid viscosity, discharge rate, and the net pressure, etc. Taking full advantages of these two factors, horizontal well multi-stage and multi-cluster fracturing becomes the mainstream technology of shale gas hydraulic fracturing, because it not only ensures multi-cluster injection through perforation optimization, but also make use of stress interference between clusters to obtain the maximum fracture networks. Moreover, in order to obtain large SRV, must apply the appropriate fracturing fluid and proppant system. The fluid system should satisfy such requirements as low viscosity, low friction, low damage, low interfacial tension, and can be mixed instantaneously and continuously with large discharge rate, etc; the proppant should satisfy such requirements as low density, high strength, low cost, different size array, and optimized transportation. Based on analysis as above, China has proposed the volume stimulation theory, and conducted field tests of 3 wells, which resulted in good industrial gas production and firm confidence in shale gas reservoir development.

Tengfei Wang holds a doctor degree from Southwest Petroleum University in 2007, and now is employed in Lang fang Branch of Research Institute of Petroleum Exploration and Development, mainly engaged in low Permeability reservoir stimulation technology research.

Add: P.O. Box44, Lang fang, He bei, P.R. China, Postalcode: 065007
Phone: (010) 69213182l, Mobile: 13472366897, E-mail: wangpfei69@petrochina.com.cn

The Key Technology to Develop Unconventional Gas – Staging Fracturing Technology in Horizontal Well

Yao Fei

Yao Fei, PetroChina

Unconventional gas has the common characteristic of extremely low permeability, and coal bed methane and shale gas exist in adsorption gas and free gas. To increase production, the seepage area must be enlarged. The effective ways to increase seepage area is to fracture the formation. Especially staging fracturing in the horizontal well will greatly increase seepage area. so as to achieve the purpose of economic and effective exploitation. Through tight sandstone gas, coalbed methane and shale gas development process, it can be seen, that the practice is along this idea. In this paper, the key technologies in developing unconventional gas are summarized.

Dr. Fei Yao is a senior production engineer working for PetroChina for more than 25 years, major in hydraulic fracturing theory, design, and the treatment supervisor. In 1985-2007, he worked in Fracture and Acidizing technology service center as vice manager later in Langfang Branch of RIPED. Since 2007, he has worked as vice manager in the Oversee Engineering Technological Center in Langfang Branch of RIPED.

He received his B.Sc from Tongji University for engineering mechanics in 2001 and Ph.D from China Petroleum University for oil and gas development engineering in 2008. He is a member of SPE.

Integrated Modeling of Hydraulic Frac Stimulation and Permeability Enhancement in Shale Reservoirs

Vikram Sen

Vikram Sen, A. (Tony) Settari, Bob Bachman & Dale Walters, Taurus Reservoir Solutions, Ltd., Calgary (CANADA)

An integrated approach to modeling shale gas wells should include simulation of hydraulic fracturing, microseismics and flow in the reservoir and wells. Within an integrated framework, this talk will emphasize the reservoir engineering aspects of the evaluation of a stimulated shale gas well.

Hydraulic fracturing is a key technique that provides commercial flow rates in horizontal wells drilled in shale reservoirs. These wells do not flow in the absence of stimulation due to the extremely low permeability of the shale matrix. Therefore, the density and flow properties of hydraulically induced fracture networks have a critical influence on well productivity. The quality of the production forecasts depends on the extent to which the flow behaviour of the stimulated zone is represented in the simulation models. There are certain similarities between modeling of wells in shale reservoirs and other tight reservoirs (sand, conglomerate etc.) - but there are important differences related to the modes of geomechanical failure in shales under the impact of massively pumped frac jobs.

Modeling of fractured wells requires specialized software that can realistically represent fracture networks in a cellular reservoir model, account for multi-phase flow (e.g. clean-up) and capture the dependencies of fracture conductivity on factors such as changing stresses in the reservoir and degradation of proppant packs with time. These considerations are applicable to shale gas wells as well as other types of tight-gas wells.

However, fracturing processes in shales can create complex networks in addition to (or instead of) simple planar fractures. Geomechanical effects (e.g. shear dilation) occur on various scales (including micro-cracks and single planar fractures) and it is difficult to predict proppant transport or conductivity in complex fracture networks. Due to the strong

interdependencies between flow and reservoir geomechanics, simple flow modeling by itself is inadequate for predicting well performance. Consequently, data from a variety of sources (e.g. completion and fracturing, imaging, clean-up, pressure transient analysis and production) must be analyzed and a coupled framework adopted for simulating the behaviour of the reservoir and wells.

Furthermore, phenomena such as desorption and flow in nanopores require the reformulation of flow equations typically used in the modeling of conventional reservoirs. This lends additional complexity to the study of shale gas wells.

Finally, direct modeling of jointed media or continuum modeling of fracturing and shear failure can be also used to predict microseismic hypocentre locations - which can be compared with processed and interpreted microseismic maps generated from frac monitoring and surveillance.

This talk will discuss coupled modeling from various perspectives mentioned above and address some of the ongoing research efforts in the area of evaluation and assessment of shale gas wells.

Dr. Vikram Sen holds degrees from the Indian Institute of Technology (Geophysics), University of Texas at Austin (Geophysics) and University of Calgary (Petroleum Engineering).

His varied experience in E&P spans geophysics (acquisition, processing and interpretation) and reservoir engineering. During 11 years with BP, he worked in the Upstream Technology Group, Gulf of Mexico Exploration and North America Gas Business Units. In his final assignment with BP, he was based in Calgary in a multi-disciplinary role studying hydraulically fractured wells in unconventional reservoirs.

Since 2009, he has pursued a full-time career as a reservoir engineer and currently has a senior consulting position with Taurus Reservoir Solutions Ltd. (Calgary, Canada) and holds an Alberta Ingenuity Research Award, studying coupled modeling of reservoirs and wells. He has also worked for Schlumberger (UK), CGG (France) and ARCO E&P Technology in Plano, Texas.

Geomechanics Issues in Drilling and Completions and Fracturing Design

David Castillo and See Hong Ong, Baker Hughes

The success of gas production from Barnett shale and other shale gas assets in the United States has created a new gas rush in the world for previously ignored gas bearing shale in the world. The key factors contributed to the success of shale gas production in the US are horizontal drilling and hydraulic fracturing. While technologies applied to shale gas asset development are not much different from those applied to conventional gas play developments, there is an increased application of Geomechanics in shale gas development. Due to the nature of tight, yet potentially fractured shale formation as the production targets, as well as the requirement of hydraulic fracturing to generate enlarged fracture network, formation mechanics properties, in-situ stress directions and magnitudes, and mechanics properties of geological features such as faults and fissures play important roles in terms of well placement (direction and length, mud weight to be used, etc), borehole stability management, fracturing designs, fault integrity analysis, and production management.

We will take a close look at how Geomechanics can be applied to optimize shale gas play development in terms of drilling optimization and fracturing optimizations, as well as optimization of long term production of these assets.

Friday, 1 April

Session 5: Microseismics for Fracture Monitoring & In-situ Stress Estimation

Geomechanics and Shale Gas Development: Relationships Among Microearthquakes, Fault Slip and Permeability Enhancement During Slickwater Hydraulic Fracturing


Mark D. Zoback

Mark D. Zoback, Professor of Geophysics, Stanford University and Senior Adviser, Baker Hughes International

In this paper we illustrate several unusual phenomenon discovered during investigation of multi-well, multi-stage slickwater hydraulic fracturing operations in the Barnett shale that may have important consequences for the development of enhanced permeability in shale gas reservoirs. Forty hydraulic fracturing stages were carried out in five parallel, horizontal wells, drilled about 500 ft apart. While the pumping rates, duration, volume of proppant in each of the stages were nearly-identical, they were carried out in a variety of sequences. With a seismic monitoring array deployed in the middle well, the frac stages in the two wells to one side were frac'd simultaneously, starting at the toes of the well and proceeding toward the heels. The two wells on the other side were frac'd sequentially ("zipper frac'd") again from the toe to the heel. In both cases, the seismic array was moved in the horizontal well to minimize the distance between the induced microseismic events and the seismic monitoring array. Finally, the middle well was frac'd in a conventional manner, with the seismic array being deployed in the vertical section of one of the wells.

After correcting for the inability to detect the smallest seismic events at larger distances, we found a systematic increase in the number of induced microseismic events with frac stage. Despite the fact that the rates and amounts of fluid that were pumped in each stage was essentially the same, the number of seismic events in a given stage increased markedly in the stages closer to the heel of the well, before dropping off right at the heel.

The shut in pressures systematically increase with distance with stage number (distance from the toe of the well). In wells A, B and C, the shut in pressure decreases from its maximum value in the stages closest to the heel of the well. The facts that both the number of earthquakes and shut-in pressures increase with stage number; there is a correlation between shut-in pressure and the number of microseismic events induced in any given stage. We are examining a variety of physical models to examine the cause of the increase in shut-in pressure with depth. These include the cumulative effects of fracture propping and poroelastic effects.

In addition to microseismic events in this data set, we've discovered long period, long duration (LPLD) seismic events. We can demonstrate that they come from the reservoir and believe they represent slow slip on faults during slick-water frac'ing operations.

The implications of these results will be discussed for estimating the stimulated rock volume during hydraulic fracturing operations as well as optimizing

hydraulic fracturing operations.

Mark D. Zoback is the Benjamin M. Page Professor of Geophysics at Stanford University. He is also co-director of the Stanford Rock Physics and Borehole Geophysics industrial consortium. Dr. Zoback conducts research on in situ stress, fault mechanics, and reservoir geomechanics. He is the author of a textbook entitled Reservoir Geomechanics published in 2007 by Cambridge University Press. He is the author/co-author of 300 technical papers. Dr. Zoback has received a number of awards and honors, including the 2008 Walter H. Bucher medal from the American Geophysical Union. He was a co-founder of GeoMechanics International in1996, where he was Chairman of the Board until 2008. He currently serves as a senior adviser to Baker Hughes, Inc.

Hydraulic Fracture Optimization in Unconventional Reservoirs

Kevin Fisher, General Manager Pinnacle a Halliburton Service

Kevin Fisher

Hydraulic fracture mapping services have led to substantial successes in many unconventional reservoirs around the world. In North America, Microseismic mapping is performed on more than 5000 fracture treatments each year and is used to optimize important parameters such as horizontal well orientation, well spacing, number of fracture stages, fracture treatment volumes and rates, stimulated reservoir volume, reservoir depth at which to land a horizontal lateral, selection of appropriate zonal isolation and staging technology strategy. Numerous operators have commented that hydraulic fracture mapping is a key technology to understanding and developing the appropriate strategies necessary to commercially exploit today's complex unconventional reservoirs.

In many unconventional reservoirs, matrix permeability is extremely low, as low as 100 nano-darcies in some gas producing reservoirs. This leads to the need for a strategy which maximizes the area of contact between the wellbore and the reservoir. Drilling and completion techniques developed recently to address these needs include horizontal drilling, multi-stage hydraulic fracturing techniques, thinner fracturing fluids with lower proppant concentrations than used in more conventional reservoirs, dense well spacing, etc. Fracture mapping services such as Tiltmeter and Microseismic have provided the data needed to make strategic changes early in the life of the field development process in order to optimize production and maximize profitability.

Pinnacle, a Halliburton Service has mapped nearly 20,000 fracture treatments with Tiltmeter and Microseismic sensors and has used these mapping results to provide better hydraulic fracture modeling, treatment designs and production results. Due to the variability in rock fabric, porosity, permeability, organic content, thermal maturity, pore pressure gradient, etc – each unconventional play and even areas within a given field may require differing strategies which can best be designed with real data from hydraulic fracture mapping. Numerous Unconventional Gas plays will be compared and contrasted in this presentation along with discussion of how the mapping results have driven different treatment designs.

The effectiveness of the fracture treatments has more to do with a low permeability well's economic success than any other event other than perhaps the choice of where to drill that well. After nearly two decades of mapping hydraulic fractures, we are still often humbled by the lack of correlation to fracture models in many areas. At one time, it was said that the industry knows almost everything about a frac EXCEPT its height, length, and direction. Today, the ability to incorporate directly measured fracture dimensions, along with fracture modeling and reservoir data, is now possible so that treatments can be fully optimized. Fracture mapping is truly a technology which integrates multiple geosciences and engineering to optimize reservoir performance. This presentation will very briefly describe several technologies used to map hydraulic fractures and will focus on real-world Unconventional Gas case histories where these mapping and modeling measurements have been integrated in order to optimize stimulations and reservoir development plans.

Kevin Fisher is General Manager of Pinnacle, a Halliburton Service and is involved today in integrating real-time fracturing diagnostics with fracture modeling to optimize the hydraulic fracturing process. He began his career with Halliburton in 1979 and served for 14 years as logging engineer, field supervisor, log analyst, US sales manager, and global technical marketing manager. He joined ProTechnics as Director of Sales and Marketing in 1993 and Pinnacle in 2000. He holds 5 U.S. patents related to spectral gamma ray, gravel pack density logging, and tiltmeter instrumentation and has written more than three dozen technical papers and articles on well logging and fracture diagnostics. Kevin has a B.S. in Natural Science/Physics from Cameron University.

Uncertainty In Microseismic Event Source Parameters Associated With A Fracture Stimulation In A Tight Sand When Using Two Borehole Geophone Arrays

Anca Rosca1, Sudipta Sarkar1, Andrew Jupe2, Julie Shemeta3, and Robert Langan1

1Chevron Energy Technology Co., Earth Science Dept., Houston, TX and San Ramon, CA, USA, 2Altcom, Ltd., Cornwall, UK, 3MEQGeo, Inc. Highlands Ranch, CO, USA

A Chevron business unit collected a microseismic data set in support of a fracture stimulation program for a gas well in tight sandstone in Colorado USA. The data were acquired with two, 12-level borehole arrays, one in each of two wells close to the well being fracture-stimulated. The geophones were nearly evenly distributed over a 122m interval for one array, and 131m for the other array. The primary purpose for using two arrays was to ensure that at least one array was able detect microseismic events, with acceptable signal-to-noise ratios, during the many stages of fracture stimulation conducted and monitored.

Thousands of microseismic events were recorded over multiple stages of fracture stimulation, and the moment magnitudes were on the order of -4.0 to -2.5. The fractures generated were vertical, as defined by the spatial distribution of events, were consistent in azimuth from one stage to another, and were confined to about a 14o azimuthal range. Their maximum horizontal extent ranged between 150m and 540m, and their vertical extent was on the order of 165m.

In order to understand the benefit of using two arrays to locate microseismic events, we focused on a single stimulation stage where the events could be seen on both arrays, which was uncommon for other fracture-stimulation stages. The arrays were on the same side of the vertical plane of fracture growth, and the distances from the stimulation well to each array location were considerably different. This resulted in a monitoring geometry that was suboptimal for evaluating the potential uplift of using two, ideally positioned arrays. The distance from the well location of fracture initiation to one array was approximately 160m and the distance to the other array was about 310m. Because the noise floor in the arrays was relatively high, we were able to identify only 15 high-quality events on both arrays for this stage.

We used both P- and S-wave arrivals, combined with P- and S-velocity models, to determine event locations using (1) the array closest to the stimulation well, and (2) both arrays together. Using two arrays reduced the major axis of the error ellipsoids (for one standard deviation) computed for velocity model and event-picking uncertainties by a factor ranging from two to four. It also eliminated the 180o uncertainty associated with a single array in determining the side on which the event occurred. By using two arrays, we had a more robust processing workflow and it also allowed us to perform

a focal mechanism analysis of some events. Therefore, using two or more arrays to monitor a given fracture stimulation stage is highly desirable and requires some pre-survey planning to determine how best to make use of the wells available for monitoring.

Anca Rosca
Education
Ph.D., Physics (Geophysics), New Mexico State University, 2000
M.S., Electrical Engineering, New Mexico State University, 2000
M.S., Physics, New Mexico State University, 1996
Diploma of Engineer, Geophysics, Bucharest University, 1988

Experience
Geophysicist, Chevron Energy Technology Co., Earth Science Department, Geophysical
Reservoir Surveillance & Seismic Imaging, 2005-Present
Visiting Scientist, Massachusetts Institute of Technology, Dept. of Earth, Atmospheric, &
Planetary Sciences, Earth Resources Laboratory, 2004-2005
Research Scientist, Weston Geophysical Corporation, 2000-2004
Geophysical Engineer, Prospectiuni S.A., 1988-1993

Bob Langan
Education
Ph.D., Geological Sciences, Northwestern University, 1980
M.S., Civil Engineering, Northwestern University, 1979
M.S., Geological Sciences, Northwestern University, 1974
B.S., Electrical Engineering, Northwestern University, 197130

Experience
Geophysicist, Chevron Energy Technology Co., Earth Science Dept, Geophysical R&D,
1985-2010
Consulting Associate Professor & Visiting Scholar, Dept. of Geophysics, Stanford University,
1993-1995
Geophysicist, Gulf Oil R&D, Geophysics Dept., 1981-1985
Postdoctoral Fellow, Civil Engineering, Northwestern University, 1980-1981
Geophysical Engineer, STS Geotechnical Consultants, 1974-1976

Other
Associate Editor, Special Issue of Geophysics, "Migration Velocity Analysis & Tomography", 2008

Fracture Monitoring by Surface and Downhole Microseismic Recording

Michael C. Mueller, MicroSeismic, Inc.


Michael C. Mueller

Microseismic monitoring from both borehole and surface or near-surface recording systems has emerged as a common method to characterize hydrofrac stimulation effectiveness and, to a lesser extent, deformation due to reservoir management processes such as depletion, injection and fluid replacement. Typically microseismic event location clouds imaged from these passive seismic recordings are then interpreted to be representative of the rock breakage processes intended during the hydrofrac stimulation, that is, as representative of stimulation induced fracturing. Patterns of event locations, source mechanisms of the events, and other event attributes such as magnitude, are visualized and combined with subsurface information and stimulation job parameters to represent the style, extent and effectiveness of the induced fracture networks. In recent years, with dramatic growth of activity in unconventional gas and oil plays in tight shales and sands, the most common approach is to monitor a series of hydrofrac stages initiated along a lateral borehole typically drilled perpendicular to the maximum horizontal stress. Induced fractures from the stimulation would then propagate parallel to the maximum horizontal stress.

The borehole-based microseismic monitoring method was the initially established standard, with recording systems comprised of arrays of geophone strings in one or more monitoring boreholes typically deployed in close proximity to the reservoir to be stimulated. The geometry of this recording system allows for detailed mapping of microseismic events associated with the stimulation based on inversion of P and S wave arrival times. Due to the proximity of the monitoring borehole to the stimulated reservoir, borehole recorded microseismic waveform amplitude is sufficient to visibly confirm hydrofrac event arrivals. The detectability of arrivals can be extended to lower source magnitudes with cross-correlation techniques. The borehole method is limited to monitoring stimulation jobs within close proximity of the recording system, typically to 500-1000m distance.

The surface and near-surface based microseismic monitoring method is newer, only being reliably established in the last few years. The surface recording system can be temporarily deployed with commonly available cable and cableless seismic recording systems at or near wellheads where hydrofrac stimulation is planned. The surface array extends radially with offset to stimulation depth ratio of 1 and feature dense sampling in offset and azimuth. A permanent version of this technique is typically deployed near-surface in fit-for-purpose shallow holes in a grid layout that is scalable to any size field or drilling program. Both surface and near-surface recording systems feature high fold and wide azimuth sampling. This allows for good illumination at target and enables imaging methods utilizing the power of stack to overcome the lack of proximal positioning to the stimulation job. Cross correlation and master/slave techniques can also be used to extend detectability to lower source magnitudes. Pre-imaging processing is utilized, as in active surface seismic processing work flows, to set recording geometry, solve for statics, detect and eliminate spurious coherent noise, balance spectra, etc.

All microseismic monitoring methods rely on calibration to constrain uncertainty in event positioning. With successful calibration, events typically can be positioned with x,y,z uncertainties less than 10-20m. Calibration for laterally extensive permanent buried array systems is typically updated as needed across the array. Calibration for borehole-based and temporarily deployed surface systems is performed for each deployment. Constraining location uncertainty via successful calibration is crucial to provide value to the fracture monitoring goal of these methods.

Mueller is the Vice President Analysis at MicroSeismic, Inc. the leading provider of passive seismic and microseismic data acquisition, analysis and interpretation to the global oil & gas industry. He has nearly 30 years of experience in geoscience technology research and development, with a focus on multicomponent seismic and seismic anisotropy. He delivered the first application of the ocean bottom seismic method at Azeri field in South Caspian (operated by BP), achieving a step change improvement in Azeri structural imaging and improved field development planning. He co-invented the dipole sonic shear anisotropy logging application which has become the industry standard for characterizing shear anisotropy in the borehole. He led a McKinsey and Company study on technology strategy and governance helping to develop and execute the strategic plan for unconventional gas resource progression and reserves production in North America for BP.

Mueller has authored numerous papers and abstracts in the area of seismic technology, two of which have been recognized by SEG editors for their fundamental contributions to the understanding and application of seismic anisotropy in the oil and gas industry. He has a B.S. in geophysics from Binghamton University and a M.S. in applied mathematics from the University of Houston.

Estimating Stress from Seismic with Applications to Unconventional Reservoirs


Ron Schmid

Ron Schmid, CGGVeritas

Unconventional reservoirs require some form of stimulation to obtain commercial production. Oil sands require heat in the form of steam and shale gas reservoirs require fracture stimulation to unlock gas from extremely low permeability formations. With respect to the latter, well completions are all about the frac. Production companies need to know basic information about factures such as will they open (and stay open), direction of fracture propagation, dimensions and type of the fracture, and will they stay in zone. At an accelerating rate, seismic data are being used to provide this type of information to guide drilling and completions.

The type of information extracted from seismic data falls into two categories, 1) geomechanical properties, and 2) principle stress measurements for v, H, and h. Deriving this type of information from seismic data rests, in turn, on a series of seismic methods including, appropriate data acquisition, careful AVAZ (Amplitude Vs. Azimuth) processing, AVO, interpolation, and inversion. Each of these methods has been with us for some time yet has been used in other contexts. For example, interpolation has been useful to fill in data unobtainable during acquisition but can also be used to populate azimuthal sectors to reduce the artifacts in azimuthal migration. The information extraction can be performed on compressional wave only data although the inclusion of shear data provides an alternate source of observations that can be used to further constrain and narrow uncertainty in the results.

A clear understanding of the geomechanical properties and their distribution explains the reservoir heterogeneity and thus the variation in economic ultimate recovery (EUR) between wells. A host of geomechanical properties can be derived from migrated CDP gathers including Young's Modulus, Poisson's Ratio, and shear modulus by first inverting the data for Vp, Vs, and density. With this information wells can be drilled in the most brittle rock which will be capable of supporting fracture stimulation and the fracture dimensions can be predicted.

Furthermore, knowledge of geomechanical properties permits the calculation of stress measurements via application of the Linear Slip Theory. Generally, the stress state is anisotropic leading to an estimation of two horizontal stresses; H and h. These estimates from seismic are dynamic stress estimates and need to be calibrated to static stress values which more accurately reflect the stress expected in the reservoir which has been subjected to long term geological processes. Once reasonably calibrated, predictions of hoop stress and closure stress can be made. At locations where the differential horizontal stress ratio (DHSR) calculated as ((H – h)/H) is low, tensile fractures will form in any direction creating a fracture swarm. If H >> h then fractures parallel to H will form. Examples will be shown that demonstrate the application of geomechanical properties and stress states to an unconventional shale reservoir.

Ron Schmid, Manager of Geophysics for the Canadian Data Library CGGVeritas. He holds a BSc. in Geophysics from the University of Calgary (1982) and an MBA (1999) as well as an executive certificate in Management and Leadership from M.I.T Sloan Business School (2008). Principle activities include ensuring clients derive maximum benefit from seismic data through application of new technology. Currently researching the extraction of in-situ stress measurements from seismic data. Past research activities include anisotropic depth migration and AVO analysis. He is a member of the EAGE, SEG, SPE, and CSEG where he has presented papers at each society as well a published in the SEG Geophysics Journal.

The Application of Microseismic Monitoring Technique in West China Oilfield


Jiaojun Rong

Jiaojun Rong, BGP

The microseismic monitoring technique is a reliable hydraulic fracturing monitoring technique; it has important guiding significance for fracturing monitoring of shale gas reservoir. This technique has developed International for many years, and has been commercialized. We started to attend and develop this technique later in china, and we have tested in part of oilfield. In this paper, we introduced the technique development status at home and abroad, analyzed the characteristics of microseismic signals and location technique. For the reservoir features of Chinese oilfields, we have done a microseismic monitoring test in the West oilfield of China, processed onsite and analyzed the feature of microseismic events when hydraulic fracturing happened. Finally, we found the microseismic events could reliably show the geometric properties of fracturing networks, this was in good agreement with other information. This test shows the hydraulic fracturing monitoring have a good application prospect in oil fields of China.

Jiaojun Rong, male, born in December 1982, engineer, graduated from the Chengdu University of Technology in July 2008 and majored in Earth exploration and Information Technology, and obtained a master's degree. Specialties: method of borehole seismic techniques and program design. Research fields: theory and application study about hydraulic fracturing monitoring technique.

Remote Sensing Applications throughout the Shale Development Cycle


Robert Brook

Kenneth (Bud) Pope and Robert Brook, Spatial Energy

The advent of the extensive shale plays across the United States has seen a sharp increase in the application of remote sensing technologies such as high resolution satellite imagery and low altitude aerial photography. Originally applied in the early stages of a project such as land management and 3-D planning, the applications have expanded into seismic processing, seismic interpretation, and well site and pipeline planning.

Specific applications discussed during the presentation will include imagery uses for well sitting to determine the position, within meters, of a drilling location; pipeline routing, including through rugged terrain and populated regions; and lineament delineation, provided through large-area imagery that depicts clues about subsurface conditions favorable for accumulating oil and gas.

In the case of the Marcellus Shale, 50cm resolution aerial photography is being collected across the entire play. The pictures are taken in autumn when the leaves are off the trees. The data is used to develop a detailed digital elevation model (DEM), and to analyze potential obstacles to future operations such as buildings, water wells, sharp elevation changes etc. The data is also used to accurately locate vintage oil and gas wells.

In seismic acquisition, the data can be used to automate operations, for example with the reduction of vibrator force output within specific distances of obstacles, ensuring a safe and efficient project. The pictures can also reveal changes in surface geology that may impact seismic data quality, with applications in acquisition, processing and interpretation.

One of the most important applications is well site planning. Large, densely placed well pad sites require detailed planning for surface water issues, and

access requirements. Much of this work can be accomplished accurately and at lower cost using high resolution remote sensing before field operations commence.

In addition to an increased availability of high resolution remote sensing data, new tools are emerging to deliver data efficiently to the geoscientist or engineer in the work place. For example, the recently introduced Spatial Image Connector (SIC) allows real time streaming of remotely stored imagery directly into PETREL. A data base is searched for publicly available data, or exclusive company owned data in the project area, and the selected data is seamlessly integrated on the fly into the coordinate system of the project. This allows all members of a team simple access to the data for every application throughout the project cycle.

By acquiring the appropriate data at the onset of a multi-year project, oil and gas companies can improve operational efficiency and safety, achieve considerable cost savings, in addition to establishing a base case surface image for later environmental impact studies, and surface restoration.

Robert A. Brook has a proven track record in the oil and gas industry for developing companies and successfully monetizing their assets. Most recently, he co-founded Zone Oil & Gas LLC and sold its Pennsylvania lease assets to Penn Virginia (NYSE:PVA) at a considerable multiple to original investment.

Prior to Zone, Mr. Brook was co-founder and CEO of Output Exploration, LLC (OPEX). The company was formed in 1999 with private equity funding led by Princeton University Endowment, and grew through a combination of acquisitions, exploration and exploitation drilling. OPEX merged into TXCO in April 2007 and its remaining assets were sold to Rosetta Resources in a transaction totaling $137 million. Prior to forming OPEX, Mr. Brook held several executive positions at Input/Output, Inc. (a leading manufacturer of seismic instrumentation), including Vice President Exploration, Vice President Research and Development, and Senior Vice President and Chief Geophysicist. He also served as President of subsidiaries OPEX, and Green Mountain Geophysical. Mr. Brook led the focus on applying new technology methodologies around mature fields, and was an early advocate and user of multi-component 3-D seismic to delineate fractures. He was also credited with the first application of under-balanced horizontal drilling in California.

Mr. Brook began his 30-year career in the industry with GSI in Saudi Arabia where he was Technical Coordinator responsible for geophysical services to ARAMCO. He later joined ARCO in Dallas as a Senior Geophysicist and then subsequently assumed his position with Input/Output. Mr. Brook is the author of numerous geophysical publications and holds two U.S. Patents. He currently serves on the Board of Advisors to Spatial Energy, a private company providing satellite imagery to the energy industry.

His professional affiliations include the Society of Exploration Geophysicists and the European Association of Geoscientists and Engineers.

Friday, 1 April

Session 6: In-situ Stress & Rock Properties

Shale Gas Stress Prediction Using Compressional and Shear Wave Seismic Data

Jon Downton, Benjamin Roure, and Richard Bale, CGGVeritas

Jon Downton

This presentation demonstrates the use of compressional and converted wave seismic data to predict lateral variations in rock properties and horizontal stress within a shale gas reservoir. P-wave prestack amplitude information is used to predict the P-wave impedance, S-wave impedance and anisotropic parameters assuming an HTI media. The isotropic parameters are used to calculate the Poisson ratio and the closure stress ratio which may be used to predict rock brittleness. The anisotropic parameters are also used to infer variations in the stress field. Alternatively the converted wave seismic data are used to predict shear wave anisotropy by estimating fast (S1) shear orientation from transverse amplitudes, rotating to fast (S1) and slow (S2) directions, then observing differences in travel time between the S1 and S2 waves. Each method has its own strengths and weaknesses in terms of vertical resolution, parameter resolution and uncertainty.

A simultaneous azimuthal elastic inversion (Downton and Roure, 2010) is performed to extract the P- and S-wave impedance along with various anisotropic parameters. The input to this inversion is azimuth- and angle-limited seismic traces. The data are modeled using an anisotropic Zoeppritz equation which generates a reflectivity series for each angle/azimuth. The resulting reflectivity is then convolved with an angle dependent wavelet and then compared to the seismic data. A Markov Chain Monte Carlo (MCMC) optimization algorithm minimizes the data misfit while honouring lateral continuity constraints and other a priori information. The algorithm incorporates a rock physics model to model the anisotropy. Two rock physics models are explored; a simple fracture model based on Linear Slip theory (Schoenberg and Sayers, 1995) and stress induced anisotropy (Gurevich, 2010). The output of this inversion can be manipulated following Gray et al. (2010) to create estimates of the minimum and maximum horizontal stresses.

These techniques are demonstrated on a shale gas reservoir from North America. The closure stress estimates (Warpinski and Smith, 1989) calculated from the Poisson ratio clearly shows lateral heterogeneity in the shale reservoir. Further the shear wave anisotropy estimate from the azimuthal inversion highlights areas of high stress corresponding to instantaneous shut in pressure measurements made along the horizontal wells. The converted wave data accurately identifies the regional and local stress directions but at lower vertical resolution than the P-wave data.

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Jon Downton is a Senior Research Advisor with CGGVeritas Hampson Russell. His main interest is reservoir geophysics and the seismic processing associated with this. Jon has presented numerous papers at SEG, EAEG and CSEG conferences, for which he has received Best Paper awards. Jon obtained his Ph.D. from the University of Calgary in 2005 and his B.Sc. in Geophysics from the University of Alberta in 1985. Jon is the Past President of the CSEG.

Rock Properties from Seismic in Unconventional Shale Gas Reservoirs

Peter Mesdag, Fugro-Jason Inc.

Unconventional shale gas reservoirs can be successfully characterized using well log and seismic data, leading to optimized well planning and higher gas flow rates.

Petrophysical analysis is used to calculate an estimated Kerogen volume based on modified Passey methods, and this volume is used as an input to a stochastic fluid and lithology modeling package. The determination of porosity, gas volume, and total organic carbon generates an accurate prediction of total hydrocarbons in place.

The next step in evaluating the potential productivity of Shale Gas reservoirs is the determination of rock properties. Poisson's Ratio and Young's modulus are essential parameters for predicting formation response to fracture stimulation. Using a rock physics modeling program that is tightly integrated with the petrophysical analysis program is the best approach for calculating the elastic properties of shale gas reservoirs.

A cross plot of Poisson's ratio versus Young's Modulus is then used to identify the more brittle rocks in the formation – typically lower Poisson's ratio and higher Young's modulus. After these rocks are identified in the logs, the next step is to use seismic data to identify these rocks between the wells.

Partial-stack seismic data can be converted to elastic properties via seismic inversion. The inversion is parameterized to produce P-impedance and Vp/Vs ratio cubes. These elastic properties of impedance and Vp/Vs can then be converted to the desired petrophysical properties of Poisson's ratio and Young's modulus.

Poisson's ratio is directly calculated from P-impedance and S-impedance. In theory, density is required to calculate Young's modulus, but in practice in many shale reservoirs, a regression fit of P-impedance to Young's modulus yields very satisfactory matches due to strong correlations between two or more rock-physics parameters in most shale reservoirs.

Once the volumes of Poisson's ratio and Young's modulus are created from the seismic inversion volume, a patented multi-volume interpretation method is applied to quickly map the areal extent and thickness of the more brittle, fracture-prone rocks within the reservoir zone. Using this information to plan well paths and frac programs can reduce drilling cost and increase production from the field.

Fred Jensen recently joined Fugro-Jason as a Petrophysical Advisor in the Application Engineering department. His experience includes…

Erik Johnson is the Marketing Director for Fugro-Jason and has been with the company for nearly 20 years. His passion is to find new ways to bring Fugro-Jason technology to bear on the problems faced by geoscientists trying to efficiently find and develop hydrocarbon resources.

Making surface seismic data more relevant for gas-shale plays

Duane Dopkin and Song ChangQing, Paradigm

The unconventional plays represent sources of huge opportunity for oil and gas companies and the global oil and gas economy. Established gas plays in stressed or naturally fractured shale formations around the world have achieved high visibility as technology plays through successful application of multiple fracture stimulations, micro-seismic data, geosteered horizontals, and new completion strategies, etc. These successes can be carried over to the emerging shale plays, creating new opportunities for the oil and gas industry to improve recovery and mitigate the cost and risk associated with drilling activities.

The technology advances to-date in these plays have largely been focused around the wellbore, with significant improvements in well completion processes, use of fracture proppants, optimizing number of fracture stages, and directional drilling. Seismic data, however, has been primarily used with traditional imaging approaches in order to better identify and delineate these shale plays. The industry has tried to extend the use of seismic geophysics with new workflows based on "azimuthal sectoring" to better determine stress and/or fracture intensity and direction.

In naturally fractured reservoirs, knowledge about the fracture matrix and stress regimes is essential. This information is naturally a "directional" problem requiring the highest levels of "directional" sampling with the seismic method. This directional data does exist in the seismic data, however current approaches (sectoring) average this information and make assumptions about in-situ measurements, compromising the quality of the results. To overcome these limitations, and to increase the relevance of surface seismic data in improving estimated ultimate recovery (EUR) in gas shale plays fields, a fundamentally different imaging approach is required to provide geoscientists and engineers with new data, interpretation techniques and perspectives that can impact their exploration and production programs. To this end, a new technology, full azimuth in-situ decomposition and imaging, which samples the subsurface in every direction in a continuous fashion is proposed for application to fractured and stressed reservoirs to secure a better understanding of subsurface stress directions and intensity. This new seismic imaging procedures creates new seismic data images that provide a novel way for interpreters to interact with seismic data and to characterize the shale plays with more confidence, more data, and with more information.

Duane.Dopkin@pdgm.com
Song.ChangQing@pdgm.com

Study on the Shale Gas Accumulation Conditions and Gas Content Calculation-Taking the Lower Paleozoic in Sichuan Basin and its Periphery as an Example

Haikuan Nie

Haikuan Nie, Research Institute of Petroleum Exploration & Production, Sinopec

Shale gas reservoir is an unconventional gas accumulation, which serves as essential factors of the petroleum accumulation system, such as source rock system, migration system, and reservoir system exist in the same shale bed. Determine the position of shale gas in the hydrocarbon accumulation and distribution spectra. From the geological features and based on the accumulation types, these oil/gas reservoirs can be divided into the "source ended members" and its vicinity (continuous accumulation) and the "reservoir ended members" and its vicinity (discontinuous accumulation), forming unconventional oil/gas reservoirs (coalbed methane, shale oil/gas, source-contacting oil/gas, water-soluble gas reservoir, etc.) and conventional oil/gas reservoirs respectively, including various types of transitional oil/gas reservoirs.

On the basis of shale gas accumulation theory and accumulation conditions, the controlling factors of shale gas accumulation were analyzed in this paper, which could be divided into internal and external factors. The internal control factors include shale geochemical indices, shale mineral composition and shale petrophysical indicators etc, which is the root cause of things to change and development, the source of the things development and determined the nature and development direction of things. The external control factors include reservoir depth, temperature and pressure of formation, etc, which only through internal control factors work. Things change and development mainly caused by the internal factors, where the depth, temperature, pressure and other external factors have little affect on things change and

development. The internal factors and external factors of the shale gas accumulation interdependence and fight each other, thus the power and status of the contradictory position changed, which both determined the shale gas accumulation. Among them the total organic carbon content, total hydrocarbon content, quartz content, clay mineral content, porosity(fracture), density, pyrite content and carbonate content of the internal controlling factors are the main factors for generating shale gas reservoir. Using the multiple linear regression between two parameters, six parameters, eight parameters and gas content to obtain the formula for gas content calculation of the shale, and the gas content between the formula calculation and the measured showed linear fit well. The more parameters using, the better it fits. The paper recommended that if conditions permitting, as much as possible using a variety of parameters to predict the gas content of the shale in order to achieve better prediction results. Early in the exploration, it proposed that using the organic carbon content and the porosity which are simple and easy to get to calculate the shale gas content.

Haikuan Nie mainly engages in research on hydrocarbon accumulation mechanism and unconventional gas geology. He holds a petroleum engineering degree (B.S. degree) and prospecting and exploration of mineral resources (M.S. degree and Ph.D. degree) from the China University of Geosciences (Beijing).

Email: niehk@pepris.com. Research Institute of Petroleum Exploration & Production, Sinopec. No. 31 Xueyuan Road, Haidian District, Beijing, China, Post Code: 100083.

Analysis on Shale Gas Accumulation Conditions in Qianzhong Uplift and Its Periphery

Qun Wu and Jian-qing Li

East Company China, SINOPEC, Nanjing Jiangsu 210019, China

Qun Wu

With the study of the Southern China tectonic and sedimentary evolutions, combining with the shale gas accumulation elements, the evaluation criteria of shale gas exploration was established based on the research of southern China shale gas region. According to shale depositional environment, sedimentary characteristics and lithologic association, Qianzhong uplift and its periphery develops three strata shale which belong to 2 types. One type is the Lower Cambrian Niutitang formation and Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi formation–mudstone/shale-siliceous shale, and the other is Upper Permian Longtan formation mudstone-muddy siltstone. Thereinto, Niutitang formation is characterized by deep burial depth, huge thickness, high contents of organic matters, high thermal evolution, and moderate brittle mineral content. The Wufeng-Longmaxi formation is characterized by moderate burial, middling thickness, medium contents of organic matters, and moderate thermal evolution.

The above two shales are the favorable exploration formations. Longtan formation is the coal bed construction, with shallow buried depth, huge thickness, high contents of organic matters, moderate thermal evolution, relatively high clay content, and both shale gas and coalbed methane developing, and is the potential favorable exploration strata. Based on the analysis of shale gas accumulation conditions, the evaluation research results show that Huang Ping–Longli blocks in the southern Guizhou Depression are the realistic and favorable areas of shale gas exploration, with a moderate depth of the Lower Cambrian, relatively stable structure, low thermal evolution of organic matters and favorable preservation conditions. At present, many active shale gas shows have been found in the drilling and outcrop sections. Qianzhong uplift develops the Lower Cambrian and the Upper Permian shales, with a stable crystalline basement, weak cover deformation, shallow depth, good preservation conditions but a high degree of organic matter evolution (influenced by Permian magmatic activity), and it is a favorable exploration area of gas accumulation and enrichment in the high evolution regions. Qianbei rift, closing to southern Sichuan depression, is a potential favorable exploration area with the development of Lower Cambrian and Lower Silurian shale systems.

Key words shale gas Qianzhong uplift accumulation condition Lower Cambrian Upper Ordovician

Qun Wu, born in 1963, senior engineer, director of unconventional department, in charge of management of unconventional resource exploration and development.

Address: 210019 6 building of Zhongtai international plaza, Jiangdong zhong road 315, Jianye district, Nanjing, Jiangsu province.

E-mail:wuq.hdsj@sinopec.com.

Shale Gas Key Experiment and Geological Evaluating Technology

HongLin Liu, Hongyan Wang, Renhe Liu, Gang Yan, and Xiaobo Li

PetroChina Research Institute of Petroleum Exploration & Development Langfang Branch

Honglin Liu

Shale gas is unconventional oil and gas resources type, which has special reservoir forming mechanism including free gas, adsorbed gas and dissolved gas, diversified accumulation conditions and widely distributed. The three gas existing status can be converted to one another in the determined temperature and pressure. Total organic carbon, gas content, mineral content, matrix permeability, porosity and gas saturation are the primary geological parameters. In this paper, the author had systematically study the shale gas lab testing method and established five series in thirty two parameter testing methods. The author has brought forward three important experiments in shale gas, including gas content testing method, matrix permeability testing method and nano-pore characterizing method. In this paper, the authors have study the relationship of gas content and buried depth and construct the parabolic model for gas content versus buried depth. The parabolic model has used in Yangzi platform for Paleozoic formation gas content forecasting and better result had acquired in selected project in Zhaotong area. After a lot of SEM observation, the author concluded that pore in shale was mainly nanometer stage pore including inter-particle and intra-particle. A lot of free gas and adsorbed gas existed in this kind of pore, which can be released during drainage.

Key words Shale gas, resources, reservoir, adsorbed gas, free gas

Since 1998, Mr. Liu has served as a geology engineer of PetroChina, a state owned company, where he serves as vice director of unconventional oil & gas lab. Mr. Wisner is also a vice director of New Energy department of RIPED-Langfang. He had devoted to unconventional gas geology and laboratory for fifteen years since he had graduated from Petroleum University.

Fracture Modeling in Shale Gas Plays – A New Method to Integrate Micro-Seismic and 3-D Seismic Attributes

Renjun Wen, Geomodeling Technology Corp.

Renjun Wen

Heterogeneity in the rock properties of shale gas plays is a major factor behind production variations in multi- stage fracture stimulation and between different wells. Is it possible to predict "sweet spots" in the shale gas plays in order to guide the planning of horizontal wells and multi-stage fracing? We present initial results to address this challenge in a new seismic interpretation workflow, in which the 3-D seismic attributes are calibrated and then correlated with micro-seismic data, the fracture stimulation model and well data. A "bi-wing" fracture model is applied to scale 3-D seismic attributes in order to account for the fracture stimulation process. This results in better correlations between micro-seismic events and fracture-related seismic attributes. Through a well-to-seismic correlation process, the seismic attributes that are most sensitive to fracture occurrence can be identified.

We have applied a "market-point process" model to characterize the spatial distribution of subsurface fractures. In this model, a fracture population is modeled by the spatial patterns of fracture points, together with distributions of fracture density, orientation, and size. Based on a power-law, or fractal model, fracture density at the sub-seismic scales can be predicted from the density of seismically mapped faults. Orientation distributions of fractures can be extracted based on stress fields or seismic attributes. After conditioning to seismic and well data, realizations of simulated fracture networks can provide insight into areas where "sweet spots" in shale gas plays can be inferred.

Dr. Renjun Wen is the founder, Chief Technology Architect, and Chairman of Geomodeling Technology Corp, an international geosciences software company in Calgary, Canada. He holds a PhD in Petroleum Geology from Norwegian University of Science and Technology, Norway (1995), and a Bsc from Jianhan Petroleum Institute, China (1983). He has published papers in the fields of reservoir modeling, sub-seismic fault modeling, geostatistical application in image processing, and seismic attribute analysis. Since 1997, Dr. Wen has collaborated with major international oil companies to develop innovative reservoir modeling software in the SBED consortium. He is a registered Professional Geologist in Alberta (APEGGA), and members of SEG, CSEG, CSPG, AAPG, SPE, EAGE, and IAMG.

Geomodeling Technology Corp., 1100, 665-8 Street, NW, Calgary, AB, T2P 3K7, Canada renjun@geomodeling.com

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